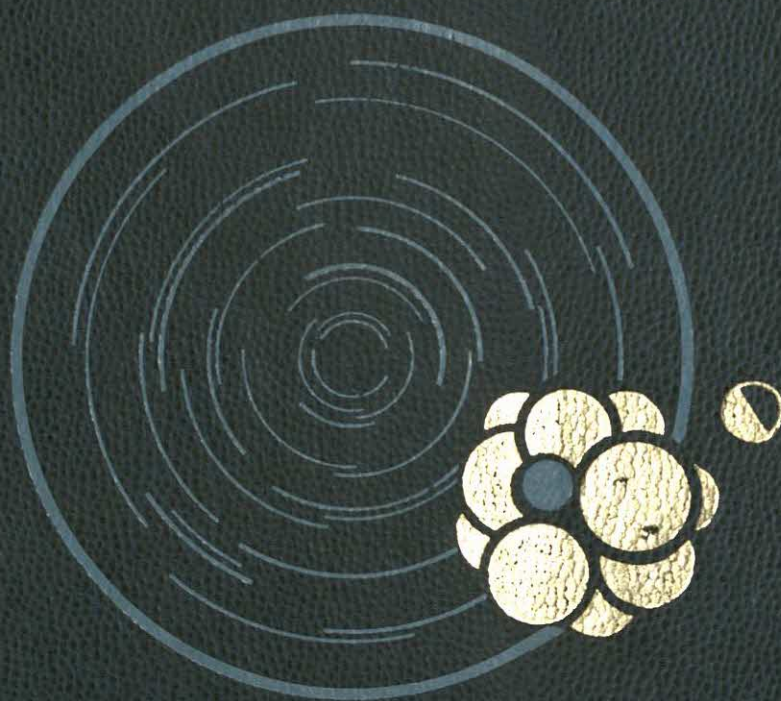


1

Illustrated World of Science Encyclopedia

Introduction
to the World
of Science:
MAN AND
HIS UNIVERSE



ILLUSTRATED
WORLD OF SCIENCE
ENCYCLOPEDIA



ILLUSTRATED
WORLD OF SCIENCE
ENCYCLOPEDIA

VOLUME 1

An Introduction:

MAN AND HIS UNIVERSE

with

The Illustrated Science Dictionary

CREATIVE WORLD PUBLICATIONS, INC.

CHICAGO

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VOLUME 1

MAN AND HIS UNIVERSE

The Illustrated World of Science Encyclopedia

- | | | | | | |
|--------|----|--------------------------------|--------|-----|---|
| | 7 | Preface | | 89 | Inside the Sun |
| PART 1 | 8 | Biology: An Introduction | | 94 | The Eclipse |
| | 9 | The Nucleus | PART 5 | 99 | Chemistry: An Introduction |
| | 12 | The Cell | | 100 | The Structure of Atoms |
| | 16 | Plant Cells | | 103 | Harmony and Disorder |
| | 20 | Life in the Temperate Forest | | 106 | Matter and Chemistry |
| | 26 | Small Creatures of the Woods | PART 6 | 109 | Mathematics: An Introduction |
| | 29 | Tropical Forests | | 110 | The Essence of Geometry |
| | 34 | Climate and Altitude | | 113 | Combinations and Probabilities |
| | 38 | Birds and Their Plumage | | 117 | Positive and Negative Numbers |
| | 42 | Nests | PART 7 | 120 | Physics: An Introduction |
| | 46 | Fish of the Deep | | 122 | Work |
| PART 2 | 50 | Man: An Introduction | | 126 | Energy |
| | 52 | The Eye | | 130 | Atoms and Molecules |
| | 56 | The Nervous System | PART 8 | 134 | Applied Sciences: An Introduction |
| | 60 | The Skin | | 135 | Engineering Giants |
| | 64 | The Muscles | | 140 | The Transmission of Electric Power |
| | 68 | The Skeleton | | 145 | Human Levers |
| PART 3 | 72 | Earth Science: An Introduction | | 148 | Television |
| | 73 | The Origin of the Planets | PART 9 | 153 | Biography: An Introduction |
| | 77 | The Origin of the Elements | | 154 | Biographies of Great Scientists
(Abel to Apollonius) |
| | 80 | Life Invades the Earth | | 161 | The Illustrated Science Dictionary
(Aa to arithmetic unit) |
| PART 4 | 84 | Astronomy: An Introduction | | | |
| | 85 | Other Galaxies | | | |

PREFACE

Today it is possible for the average family to sit in the comfort of its living room and watch astronauts return to Earth from the moon nearly 250,000 miles away. This vast distance can now be covered in three days—and already plans are being made for further space explorations to Mars, Venus and even beyond.

By splitting the atom, it is theoretically possible to extract light for all our cities. By working with petroleum, we can produce a plastic material strong enough to resist gun bullets. In hospitals, the laser beam has already performed medical miracles.

Truly, our lives have been permeated and conditioned by the extraordinary progress of science and technology. The daily papers are constantly reporting breakthroughs in every field; indeed, the communications media are continually introducing into our lives a steady stream of information, pictures and pertinent data on these scientific events. The many everyday things that we use out of habit, very often with total indifference, are often the result of highly advanced studies. Even our daily health has become dependent on scientific progress.

And yet, despite the immense role it plays in the life of each one of us, science and its incredible number of applications are seldom discussed intelligently, if at all, by the average person. It is difficult to believe—despite the abundance of information available—that there are people who remain totally unaware of these scientific advancements, even of such things as the new drugs and surgical techniques that could save their lives. Moreover, science has become an important instrument of national power; it determines, to a great extent, the political climate of the entire world. The only meaningful defense for a country in today's power structure rests in its thorough knowledge of science and the quality of its research facilities, without which it cannot plan for a secure future.

This encyclopedia has been prepared for all those who want to enter into the spirit of modern science. But science itself has become so specialized that it is extremely difficult to find a text that gives clear explanations of the myriad bases (and their applications) that make possible the constant march forward of science. We have attempted in this series of 20 volumes to provide such explanations—and in a way that enables each reader, regardless of his scientific background, to consider questions that are both difficult and foreign to him.

In the first place, we have treated each of the basic sciences as a unit rather than arrange hundreds of diverse subjects alphabetically; thus, each major subject is treated as a whole. We have, furthermore, presumed throughout

that the reader has had little or no previous training in the topics discussed. For this reason, we have tried to avoid the use of technical or unusual terms without first defining them. While the majority of the articles within each category are meant to be read in sequence, each individual piece may be read and understood without having seen the preceding article. In this way, the set may be used for both casual reference and serious study.

We have also tried to make the greatest possible use of illustrations. Sketches have been inserted to help readers understand the principles on which a demonstration is based; diagrams are frequently used to explain the functions of complex mechanisms; and step-by-step outlines help inform readers about those subjects that cannot be illustrated.

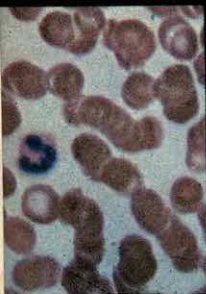
Several other unique features in *The World of Science* should be brought to the reader's attention. In Volumes 19 and 20, we have prepared some 500 biographies of the world's greatest scientists, arranged alphabetically so that you may easily locate each individual. In Volumes 17 and 18, nearly 100 different subjects in the field of applied science—from the automobile to the x-ray—have been arranged alphabetically; here readers will find useful information about many of the practical applications of scientific theory.

For those who want to look up a specific subject—who may be uncertain, for example, whether the topic they are looking for belongs in the volume on chemistry or physics—a complete index has been provided in Volume 20. It covers every major and minor subject in the 20-volume set.

And finally, in the back of each volume we have provided a special 32-page section taken from *The Illustrated Science Dictionary*, an alphabetical arrangement of more than 3,500 entries. If, for example, you wish to look up *zygote*, you turn first to the dictionary section that includes the "Z" words (Volume 20). Here you learn the basic definition of *zygote*. Then, if you decide you want to know more about that subject, simply turn to the index to find all of the articles in which *zygote* has been mentioned. By following this simple procedure each time, you will discover that *The World of Science* is a world indeed of interesting, useful facts and beautiful, colorful things.

In Volume 1—MAN AND HIS UNIVERSE—which follows, we have assembled a sampling of each of the basic units found in the complete set. These articles are designed to give you a taste of what is to come; they will also provide each reader with enough basic information so that he may gain an intellectual foothold in whatever subject area he may wish to investigate.

—THE EDITORS



PART 1

9	The Nucleus	29	Tropical Forests
12	The Cell	34	Climate and Altitude
16	Plant Cells	38	Birds and Their Plumage
20	Life in the Temperate Forest	42	Nests
26	Small Creatures of the Woods	46	Fish of the Deep

BIOLOGY | a science of diversity within unity

No one can study living creatures for long without noticing the continual recurrence—with fascinating variations—of certain themes. Among these are the basic structural and chemical *unity* of all forms of life; the *diversity* of form and function within this unit, a diversity that permits living matter to occupy a *multitude of environmental niches*; and the continuous *recycling of elements* up and down the evolutionary scale of organisms.

In this introductory volume, the first articles—"The Nucleus" (p. 9) and "The Cell" (p. 12)—stress unifying structural entities: chromosomes, nuclei, membranes, mitochondria, cells, tissues. Yet even at these levels, numerous examples of diversity exist: variation in chromosome number, in cell size and shape, and in cell function. Consider the fact, as revealed in "The Cell," of the two-million-fold difference in size between small bacteria and long nerve cells, or the difference in function of white blood cells and esophageal epithelial cells.

The specialized structures that have evolved in plant cells are summarized in "Plant Cells" (p. 16). The differentiation of cell structures to permit specialized tissue functions is described; also emphasized is the chloroplast, an organelle important to both plants and animals.

"Life in the Temperate Forest" (p. 20), "Small Creatures of the Woods" (p. 26), "Tropical Forests" (p. 29), "Climate and Altitude" (p. 34), and "Fish of the Deep" (p. 46) illustrate the great variety of geographic, climatic, and ecological niches occupied by living organisms, large and small, vertebrate and invertebrate, plant and animal. The interaction of carnivorous and herbivorous animals in the temperate forests, the annual cycles of rebirth, maturation, senescence, and hibernation of plant and animal in these regions, and the impact of man's intervention are portrayed in "Life in the Temperate Forest." An added theme is

heard in "Small Creatures of the Woods": the cycling by small creatures—invertebrates and microorganisms—of atoms and molecules from dead plant and animal tissue back to useful elements.

In "Tropical Forests," "Climate and Altitude," and "Fish of the Deep," attention is shifted to less familiar geographic and climatic environments: tropical forests, deserts, mountain peaks, and the ocean depths. We learn that the rigidity of the abyssal waters slows the metabolism of its silent inhabitants, whereas in the tropical rain forests, bamboo shoots may grow at the rate of 14 inches per day! To obtain light for photosynthesis, giant vines more than 500 feet long grow from the ground upward on trees and compete with the latter for a place in the sun. Contrast this struggle with the deep sea animals that make their own light. Of course, these animals need light not for photosynthesis but rather for simple illumination, for luring prey, or for other reasons yet to be discovered.

A group of fascinating creatures are considered in "Birds and Their Plumage" (p. 38) and "Nests" (p. 42). Feathers have several functions: aeronautical, insulatory, protective, camouflage, sexual identification, and as nesting material; feather structure has evolved to accommodate these various needs. About as many types of nests exist as types of birds; the concern of birds in nest building ranges from none (terns), to the use of other birds' nests (cuckoos), to the elaborate architecture of orioles and swallows.

In Volumes 2 and 3, both devoted to biology, there is further evidence that, although all forms of life have a common basic structure and a number of identical functions, they have become remarkably diversified. Because of this, they are enabled to accomplish specific tasks in the environments in which they have evolved. Such is nature's marvelous legacy to the living things that inhabit our Earth.

THE NUCLEUS | the coordinating center of cellular activity

The cell—the fundamental unit of life—is the seat of vital activity for every living thing. A living, unstained cell often appears to be clear or uniformly granular; but in some cells—especially those that are properly stained—a single body is clearly evident. This body—the governing center of all cellular activity—is the nucleus. Without it, no cell can survive long; like an animal without its head, an unnucleated cell must die.

The amoeba, a microscopic unicellular animal that lives in both fresh and salt water, has been the subject of many nuclear experiments. When its nucleus is removed, the rest of the cell continues to move, but soon it becomes insensible to changes in its environment. While it can still perform certain essential biochemical processes, such as respiration, and for a short time it is able to absorb some compounds from its environment, its ability to utilize them gradually declines.

Under these conditions the cell soon dies. If cellular activity has not declined too greatly, the cell may be restored by returning the nucleus to its place in the cytoplasm (the nucleus that is returned must be a living one, of course). When a nucleus is separated from its cytoplasm, it, too, lives for only a few hours.

A few cells lose their nuclei naturally in the course of their development. One such cell is the red corpuscle of mammalian blood; when it is formed in the bone marrow, this cell has a nucleus—but this disintegrates before the cell is released into the bloodstream. Without a nucleus, the red corpuscle cannot divide and eventually dies (in about 110 to 130 days in humans). It is replaced by new cells formed in the bone marrow.

The form of the nucleus is generally spherical, although it may be deformed by the shape of its cell. In cylindrical cells—such as those of pollen tubes, for

example—the nucleus is elongated. Under the microscope the nucleus usually appears as a small, rather compact mass. Some white corpuscles have nuclei with lobes that appear to be almost completely pinched off from each other.

Usually, each cell has only one nucleus, but certain cells, such as those of the liver and of some fungi, may be binucleate (having two nuclei); others, such as those of other fungi and the unicellular animal *Paramecium*, may be polynucleate (having many nuclei).

COMPONENTS OF THE NUCLEUS

Like the cell, the nucleus is not a homogeneous mass, but is made up of several components surrounded by the nuclear membrane. The interior of the nucleus consists of a liquid called karyolymph, or nuclear sap, in which are suspended one or more nucleoli and the chromosomes.

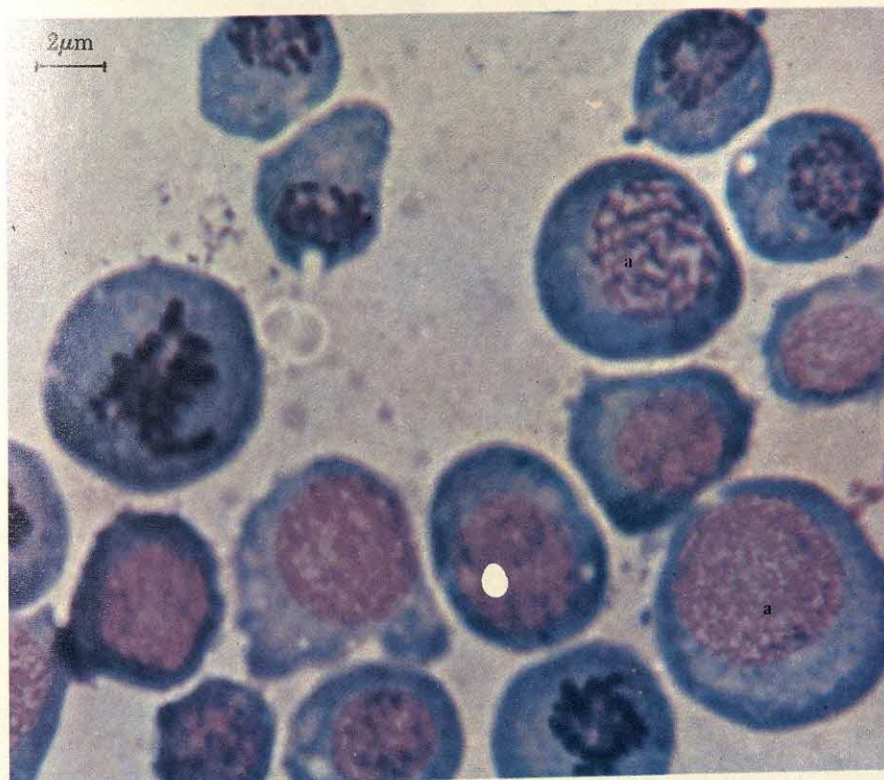
Nuclear membrane. The nuclear membrane envelops the nucleus in a thin film and regulates the passage of materials into and out of the nucleus. The membrane has a large number of openings, or pores, through which substances are exchanged with the cytoplasm. Under the electron microscope the membrane is seen to consist of two distinct layers, each composed of proteins and lipids (fatlike compounds). The outer layer is often continuous with the endoplasmic reticulum, a membrane system within the cytoplasm.

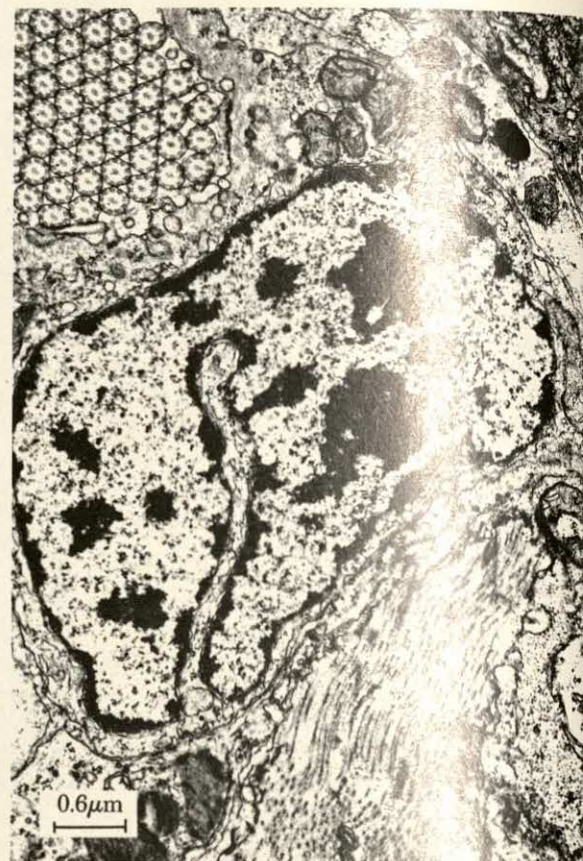
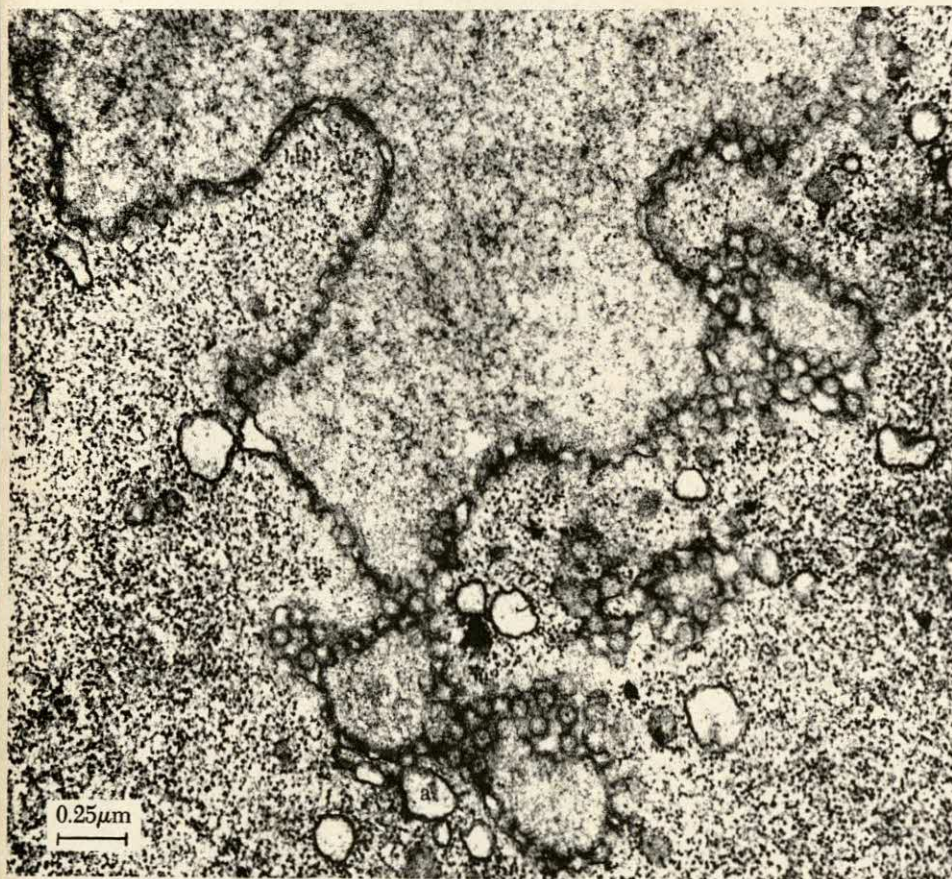
Nucleolus. Inside each nucleus is at least one nucleolus (some nuclei have two or more nucleoli). The nucleolus is clearly distinguishable from the other components of the nucleus: it is a rather compact mass approximately spherical in shape, and it has a rather heterogeneous aspect, with opaque and transparent zones. Its boundaries are indistinct because it has no limiting membrane (Illustration 4). The nucleolus is rich in RNA (ribonucleic acid), a compound that, when transported to the cytoplasm, controls the synthesis of proteins.

Chromosomes. Within the nucleus are

MEGALOBLASTS OF A CHICKEN EMBRYO—Blood cells in a growing phase, megaloblasts are spherical with spherical nuclei. The chromatin is clearly evident. (Stain: May—Grunwalds—Giemsa)

matin is clearly evident. (Stain: May—Grunwalds—Giemsa)





NUCLEAR MEMBRANE—The pores *a* are clearly evident in this electron micrograph. These are the fine canals that pass through the membrane, at upper right (Illustration 2).

FLAME CELL OF PLANARIA—Electron micrograph of nucleus surrounded by its nuclear membrane (Illustration 3). A tuft of cilia appears in cross section at upper left.

CELLS OF THE HUMAN INTESTINE—The large nuclei have somewhat irregular shapes and appear pale in the electron micrograph. Each contains one dark nucleolus. (Illus. 4).



GIANT CHROMOSOMES OF THE FRUIT FLY DROSOPHILA—The dark bands, which are rich in DNA, alternate with light bands.

several long threadlike bodies, the chromosomes. In most interphase cells (cells that are not dividing), the chromosomes are hardly evident, but they are easily seen in interphase cells of the salivary glands of the fruit fly (Illustration 5). In dividing cells, the chromosomes become shorter, thicker, and more easily visible. The chromosomes contain the genes, which consist of DNA (deoxyribo-

nucleic acid), the genetic material that transmits hereditary traits (such as hair color) or the predisposition to certain hereditary diseases. Chromosomes also contain proteins.

Each nucleus contains a definite number of chromosomes that is characteristic of the species. Except for reproductive cells, the chromosomes occur in pairs, and the total number of chromosomes per nucleus is known as the diploid number. Eggs and sperms have half that number—the monoploid (or haploid) number. Humans have 46 chromosomes arranged in 23 pairs in the nuclei of all

diploid cells; the eggs and sperms are monoploid with 23 chromosomes per nucleus. If, by accident, a cell receives an extra chromosome, serious consequences may result. Down's syndrome, sometimes called mongolian idiocy, is a type of mental deficiency caused by the presence of an extra chromosome of one particular pair. Humans who have extra sex chromosomes have unusual sexual characteristics. Individuals with three X chromosomes are abnormal females, while those with two X chromosomes and a Y chromosome (Klinefelter's syndrome) are underdeveloped males.

THE CELL | the basic unit of life

The obvious difference between a stone and a plant or animal is the simple fact that the stone is a "dead" object, while the plant and animal are living things. Despite this obviousness, however, few observers ever ask themselves *why* this difference exists.

To begin, the stone does not have life, of course; it is a static mass that does not change except by the application of external forces, and it does not produce new stones like itself, except possibly by being broken in two. The plant and animal are subject to biological cycles that involve continuous internal transformations. They are produced from their parents: they grow, they reproduce, they age, and they die. During their lives they adapt as necessary to changes in their environments.

Plants and animals are composed of

units, each of which is able to perform for itself many or all of its vital functions. These units are known as cells. A cell is the smallest morphological and functional unit capable of autonomous life. Each grows, adapts, and usually reproduces; each absorbs food from its environment, utilizes the food in a complex of chemical reactions, and eliminates the waste products. Groups of cells of the same kind often form aggregates known as tissues, such as muscle tissue or nerve tissue.

Tissues, in turn, are united into organs—such as the stomach, the eyes, the heart, or the liver of an animal, and the roots, stems, or leaves of a plant. Within an organ are several tissues that function together as a larger unit. For example, the nerves, muscle tissue, and digestive glands of the stomach all contribute to

the efficient digestion of food in the stomach.

The multicellular organism is a still larger unit that functions well because of the integrated behavior of its organs, but ultimately it depends on the activities of its individual cells.

DISCOVERY OF THE CELL

In 1665, while observing a thin slice of cork under the microscope, the English physicist Robert Hooke noted that it was made up of small, empty compartments that were distinct from one another (Illustration 8). Hooke called these compartments "cells." The cells in cork are not typical cells, however, because they are dead and consist only of cell walls surrounding empty space.

Later scientists discovered that live

2



1



STONES—These objects are the most common representatives of the mineral kingdom, a completely inanimate world.

FIR TREE—A plant that grows in cold climates (the Alps and northern Europe), the fir is one of the most typical examples of the plant kingdom.

JAGUAR—This feline is representative of the animal kingdom; it lives in tropical forests.

3





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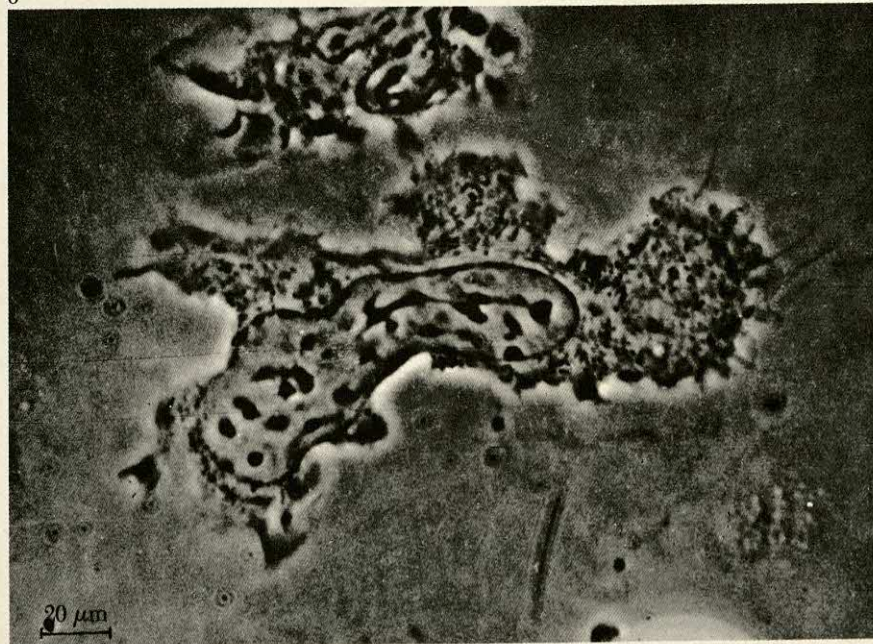


PARAMECIUM—This microscopic unicellular organism (*Protozoa ciliata*, Illustration 4) is found in stagnant water.

ALGAE—The unicellular organisms (*Euglena viridis*) shown in Illustration 5 are commonly found in both fresh and stagnant water.

AMOEBA—The unicellular organism (*Protozoa sarcodina*) shown in Illustration 6 takes on extremely varied forms in the water.

6



cells contain a semiliquid substance that was named *protoplasm* in 1835 by Dujardin, a French scientist. Protoplasm, a word of Greek origin, means literally “first form”—that is, the prime matter that represents the basic substance of life. It is known today that protoplasm is not a simple substance but is a complex of

many compounds, some of them organized into organelles. The term “protoplasm” is still used to describe all the living material in a cell.

In 1838 the German biologists Schleiden and Schwann advanced the cell theory, according to which all living things are divisible into basic units: the

cells. According to the theory, life does not exist where there is no cellular structure. Viruses, which were discovered in 1898, offer one possible exception to the cell theory; for viruses have no cellular structure but consist primarily of nucleoprotein. On the other hand, they do have some properties of living things, includ-

ing the ability to reproduce and to change, or mutate.

Cells have extremely varied shapes: round, cylindrical, flat, stellar, and so forth. They have numerous shapes because they perform numerous functions in the organism, and they take on the form most suited to their function. The cells of the skin and epithelium are flat, which enables them to unite into a compact covering tissue and adhere firmly to one another (Illustration 10). Nerve cells have a stellar form; the several elongated processes that extend from them collect and transmit nervous impulses from even the farthest parts of the body (Illustration 11).

A cell's dimensions can vary from a fraction of a micron (a micron, which is equal to one-millionth of a meter, is designated by the symbol μm) to much greater sizes. Some bacterial cells have diameters of a half micron or less. The yolk of an ostrich egg, which is a huge single cell, exceeds other living cells in volume, but the fine fibers in plant stems and the slender nerve cells in animals may be more than a meter long.

Protoplasm, the living material of the cell, is made up of two basic parts: the cytoplasm, in which many chemical reactions occur, and the nucleus, which controls these activities. Cytoplasm is delimited by the plasma membrane,

which is the outermost boundary of the cytoplasm (and therefore also of the protoplasm). The plasma membrane, through its differential permeability, controls the movement of many materials into or out of the cell. Plant cells are surrounded by a cellulose cell wall that lies just to the outside of the plasma membrane. The cytoplasm contains several distinct organelles (Illustration 12): mitochondria a; Golgi apparatus b; centriole c; ergastoplasm d; and lysosomes e.

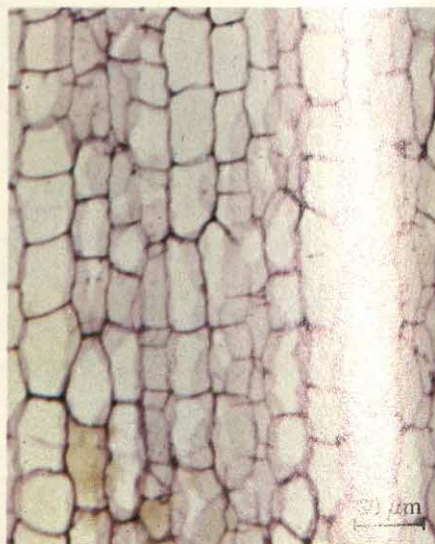
The nucleus is bounded by the nuclear membrane f, the chromosomes, and the nucleolus g. The chromosomes are especially important because they contain the genetic material of the organism.

7



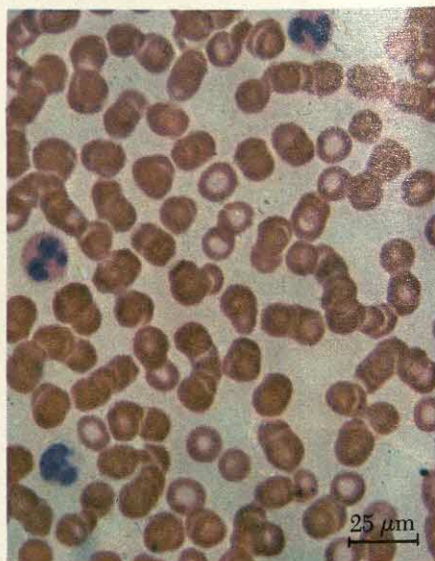
COMPOUND MICROSCOPE—This modern microscope directs light upward through a specimen that lies over a hole in the stage. The objective and eyepiece enlarge the image of the specimen.

8

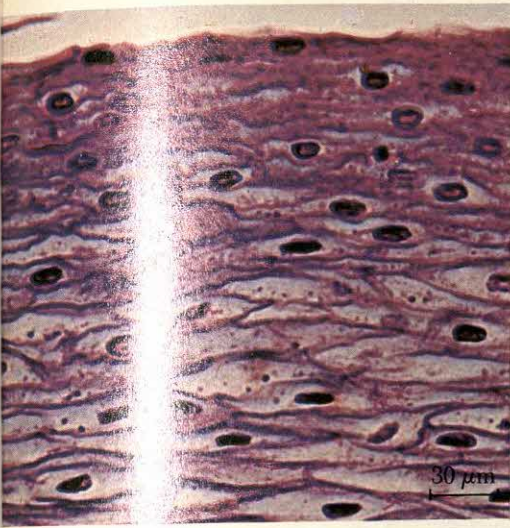


SECTION OF CORK—The cell walls are clearly evident, but the protoplasm is no longer present in these dead cells.

9



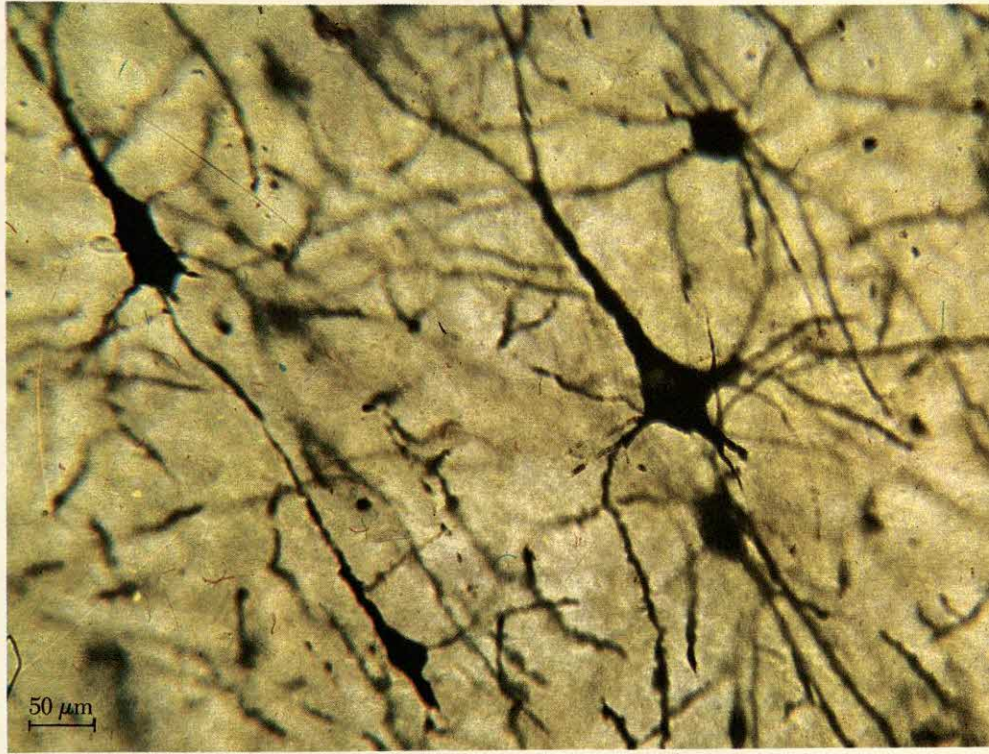
RED AND WHITE CORPUSCLES—These white corpuscles, stained purple, represent a sample of human blood.



STRATIFIED PAVEMENT EPITHELIUM OF THE HUMAN ESOPHAGUS—Note that the cells are flattened and contiguous.

CEREBRAL CORTEX—The cells that make up nerve tissue have a typical stellar form that easily distinguishes them.

A CELL UNDER THE ELECTRON MICROSCOPE—Here the nucleus, nucleolus, mitochondria, Golgi apparatus, ergastoplasm, and centriole are all visible.



PLANT CELLS | self-sustaining units of life

Plant cells share many common properties with the animal cells, and together they are responsible for the unity of the entire living world. Plant cells, however, have special organelles related to the type of life that the plant leads—organelles that are lacking in animal cells. These structures include a cellulose cell wall, plastids, and one or more vacuoles.

Many plant cells differ from animal cells in that they are capable of manufacturing the food they require. For this reason most plants are known as autotrophs—organisms that feed themselves. Man and other animals are, on the other hand, heterotrophs—organisms that require food synthesized by plants.

THE CELL WALL

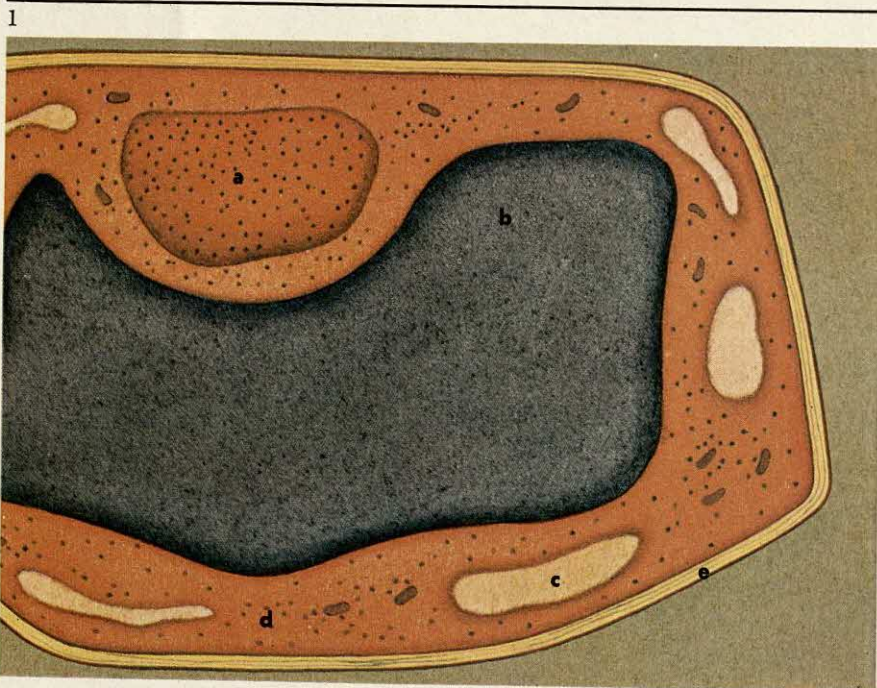
The plant cell is surrounded by a wall composed mostly of cellulose—a wall that

is formed by the cell itself. When a cell divides, an extremely thin layer called the cell plate forms between the two daughter cells; and on either side of the cell plate a primary cell wall develops consisting of cellulose. The primary cell wall is elastic and stretches as the cell grows and increases in volume.

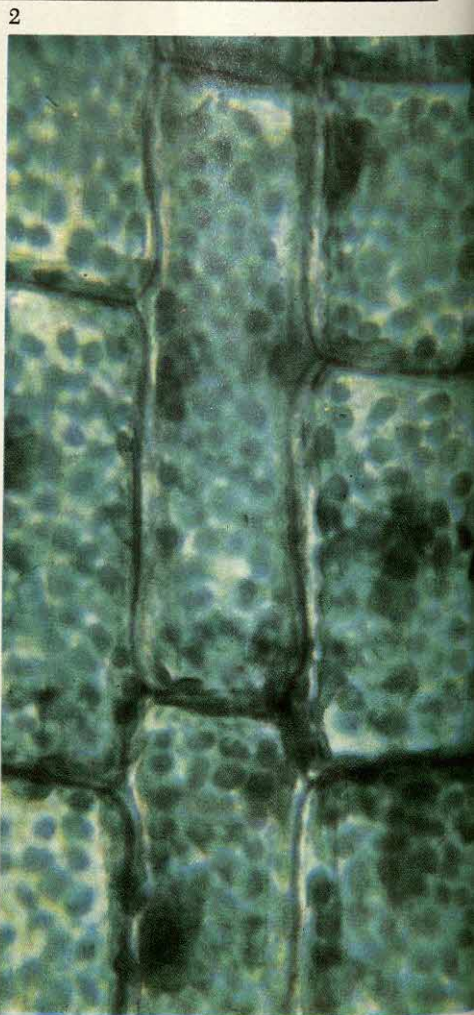
Small openings in the primary cell wall permit the exchange of materials between cells. Later, as the cell matures, a secondary cell wall may or may not form on the inner surface of the primary cell wall. Secondary cell walls contain some substances in addition to cellulose; in wood, for example, they contain lignin, a substance that contributes strength and hardness to the tissue. One of the functions of wood is the transport of water through the entire plant. Lignin itself is impermeable to water, but the secondary cell walls have openings, or pits, through

which water can pass. In some wood cells, the secondary walls take the form of rings or helices.

The outer tissues of plant organs are either epidermis (in leaves, young stems, and young roots) or cork (in older stems and roots). The secondary cell walls of epidermal cells are impregnated with cutin, a waxy substance, and those of cork contain suberin, a substance similar to cutin. Both cutin and suberin are impermeable to water, and thus they prevent loss of water from the plant by evaporation. Cutin, which is especially thick on the epidermis of desert plants, is usually thin on water plants. Corks are used to seal bottles because their high suberin content prevents leakage or evaporation. In its restricted, commercial sense, however, only bark of the cork oak (*Quercus suber*) and its varieties merits designation.



A PLANT CELL—A mature plant cell contains a nucleus **a**, a vacuole **b**, mitochondria **c**, cytoplasm **d**, and a cell wall **e**.



GREEN PLANT CELLS—The green pigment chlorophyll contained in many small disk-shaped chloroplasts is responsible for the color of these cells (Illustration 2).

PLASTIDS

The plastids are organelles that are scattered throughout the cytoplasm of the cell. Plastids can be divided into three types: chloroplasts, chromoplasts, and leucoplasts.

Chloroplasts are green because they contain chlorophyll; they give plants their characteristic green color (Illustration 2). Under the electron microscope, chloroplasts are seen to have a typical lamellar structure formed of membranes consisting of proteins, lipids, and chlorophyll. These lamellae have a basic function in photosynthesis, the process by which the plant cell manufactures carbohydrates. The lamellae are organized into small disk-shaped units known as grana. The function of chlorophyll is the absorption of light, which is the energy source for photosynthesis; thus, plastids are the

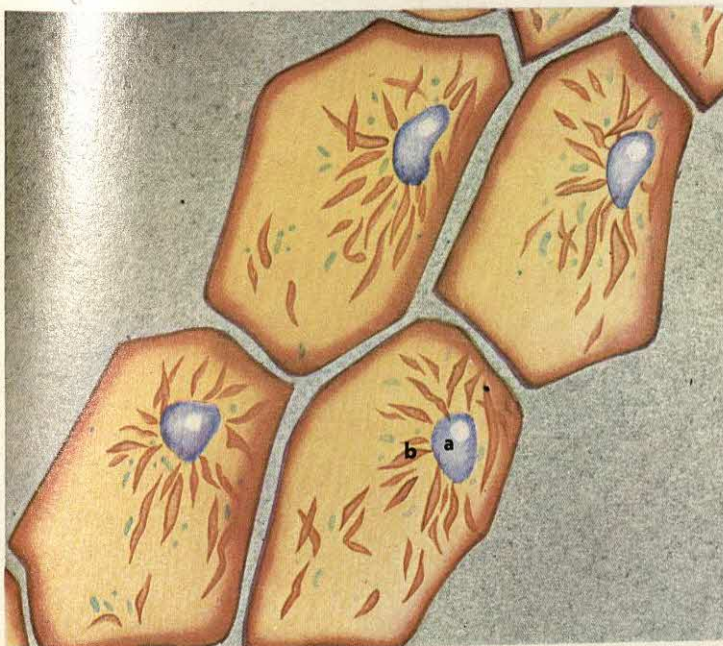
only site of photosynthesis. Light is also necessary for the synthesis of chlorophyll. Plants grown in sunlight are usually green; those grown in the dark become yellow because their chlorophyll disintegrates.

Chromoplasts are plastids containing pigments other than chlorophyll—usually red and orange ones. They give color to some fruits, vegetables, and flowers. Carrots (Illustration 3), tomatoes, and red peppers owe their colors to chromoplasts, which have no other known function. Leucoplasts (Illustration 4), which are colorless, store foods synthesized by the chloroplasts. Starch is a commonly stored food, but oils are sometimes stored in leucoplasts. Leucoplasts are located especially in such underground organs as roots, tubers, and rhizomes. When food is needed in other parts of the plant, the food in the leucoplasts goes there.

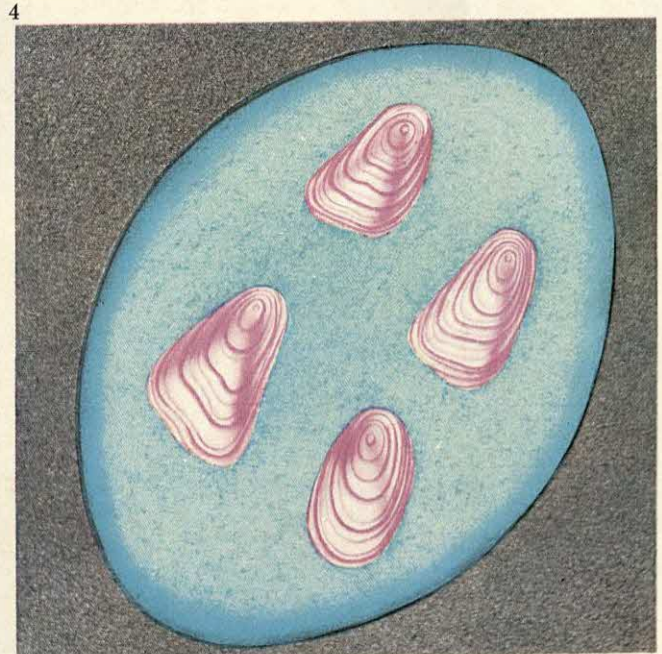
VACUOLES

In its cytoplasm each plant cell contains one or more small, water-filled cavities, known as vacuoles. A young plant cell has many small vacuoles, but as the cell matures, they merge into a single large vacuole that occupies nearly the entire volume of the cell.

The vacuole contains a variety of water-soluble substances including sugars, minerals, gases, and some pigments. The colors of apples and geraniums are due to vacuolar pigments rather than plastid pigments. As cells absorb water, their vacuoles become larger. The growth of young cells with elastic cell walls is due largely to absorption of water. In older cells having rigid cell walls, this absorption of water increases the turgidity of the cells and of the tissues of which they are a part.



CHROMOPLASTS—The orange color of the carrot is due to the presence of chromoplasts **b** in the cells. The nucleus **a** is colored blue.

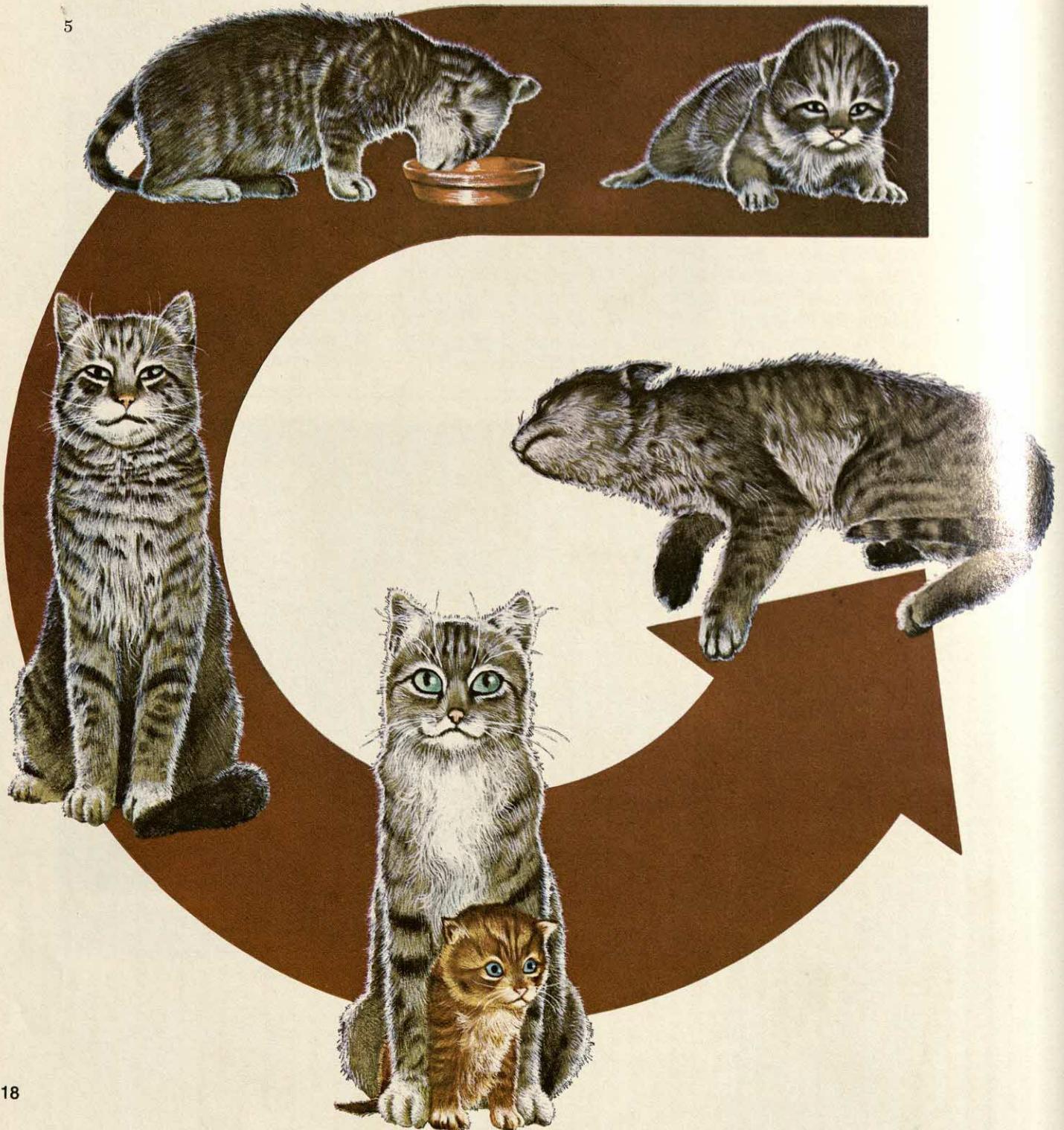


STOREHOUSES OF STARCH—The leucoplasts are colorless because they contain no pigments. They are found in most parts of the plant, and usually each one contains a single

starch grain. The shape and the pattern of surface markings vary with the species. Shown here are four starch grains from a cell of a potato.

THE PHASES OF LIFE—This diagram represents the basic phases in life and illustrates the meaning of the words "to live." An animal is born, it eats, it grows, it reproduces, and it dies. Plants germinate, form green leaves in which they synthesize food, produce offspring, and eventually die. Death is actually no more than the final phase of life, the con-

clusion of the biological cycle that each organism, whether animal or plant, must undergo. As the great scientist and philosopher Albert Einstein said, "To be conscious of the mysteries of life is the most beautiful sentiment that we can have. It is at the heart of all art and all true science."





LIFE IN THE TEMPERATE FOREST | a new appearance for every season

Although man has extended his dominion from the torrid tropical zones to the frozen regions of the Antarctic, he seems to prefer living in the temperate zones, the two belts that lie between the tropics and the polar regions, and that have four seasons annually.

Temperate forests occur in those areas of the temperate zones that have more than 750 mm (about 30 in.) of rain per year. In the colder and drier parts of these areas, the trees are predominately coniferous; in the warmer and wetter parts, the dominant species are deciduous, broad-leaved trees. To the unobservant, deciduous woods may all seem alike, with a mixture of walnut, oak, maple, chestnut, ash, beech, and elm trees. Actually, deciduous woods form a rather complex world in which botanists have distinguished many communities of plants in which only two or three species are dominant.

Most temperate deciduous forests are north of the equator, for most of the South Temperate Zone is covered by oceans. Three large deciduous forests exist in the North Temperate Zone: one covers nearly all of the eastern United States; the second extends in a narrow band across Europe from the British Isles to western Asia; the third covers most of Japan, Korea, and China. Unfortunately, man has destroyed vast areas of temperate forests in order to bring the land under cultivation, and only a small fraction of these woods exist in their original state.

Despite the name, much of the area in the temperate zones is not actually temperate. Midsummer heat can be tropical, and the winter cold can be frigid. Plants and animals must be able to adapt to these changes. Spring blossoms, the intense green of the summer, the fantastic colors of autumn, and the stark nudity of winter, are only tokens of the sometimes violent extremes of the seasons.

In the temperate zones, one of the greatest environmental challenges to



FLOWERS AND TREES OF THE TEMPERATE FOREST—The temperate forest offers a variety of aspects, forms, and colors. At the beginning of each season, the appearance of the forest changes. Here are three different flowers that are quite common in the undergrowth in springtime: Illustration 1a shows a lily of the valley (*Convallaria majalis*); Illustration 1b, a large hawthorn bush (*Crataegus*

oxyacantha); and Illustration 1c, a bunch of violets (*Viola hirta*). Like all other flowers of the underbrush, they emerge at the beginning of spring, when the trees are still bare, and the sunlight can reach the forest floor. Illustrations 1d and 1e show two different aspects of a forest in its lush summer clothing, while in Illustration 1f, the leaves begin to grow red and fall in an autumn woods.



1d



1e



21

ANIMAL LIFE IN THE FOREST—Illustration 2a shows a squirrel (*Citellus lateralis*), a rodent found throughout the world except in Australia. Its characteristic feature is its long, bushy tail. In Illustration 2b is a fine specimen of a stag (*Cervus elaphus*). A male green wood-

pecker (*Picus viridis*) is shown at its nest in Illustration 2c, about to feed one of its young. Illustrations 2d and 2e show a young hare (*Lepus europaeus*) and a raccoon (*Procyon lotor*).



plants is the lack of water during the winter. The freezing of soil water results in physiological drought, for the plants cannot utilize ice. At the same time, the dry winter air hastens the evaporation of water from plant tissues. During this time, plants go into a dormant state in which there is almost no growth and very little need for water. Leaves are the main organs through which water is lost, and deciduous plants drop their leaves in autumn, remaining leafless during the winter. The evergreen conifers have small needle-shaped leaves with only a small amount of surface area through which



water can evaporate. The trunks and branches of both types of trees are protected from drying winds by their thick bark.

In the spring, when the first warm spells free the Earth from the icy grasp of winter, the roots of the forest plants begin to grow and to absorb the water running off from melting ice and snow. This stimulates the development of new shoots. One of the first plants to bloom is the skunk cabbage; it is soon followed by anemones, crocuses, lilies of the valley, primroses, and violets. Most of the spring wild flowers bloom before they

are shaded by the expanding leaves of the trees. Some trees, such as poplars and willows, bloom before they produce leaves.

By summer, plants are in full leaf, and the dark green color of the foliage dominates the forest. Photosynthesis usually forms an excess of sugars that allow seeds and fruits to ripen. Reserves of starch accumulate in the roots, bulbs, and rhizomes of perennial plants; these reserves are stored over the winter and nourish the burst of growth early the following spring.

In autumn, the pure green of the



leaves fades and slowly gives way to the red and yellow colors typical of deciduous forests—especially in eastern North America and eastern Asia where, for a few days or weeks, the woods are a mass of rich colors. Soon afterward, the leaves are detached and fall to the earth, bringing the cycle full circle. In November, a rust-colored carpet of leaves covers the floor of the forest, and the branches stand out against the autumn sky in a stark geometry that seems to anticipate the white silence that will reign during the winter months.

Many animals live in this changeable plant kingdom. In autumn, they migrate toward warmer regions, enter into hibernation, or grow thick coats that protect them from the rigors of winter. Many of these animals are so rarely seen that their presence can be detected only by their footprints in the snow.

For most of the animals of the wood, spring coincides with the birth of young. Fur-bearing animals change their winter coats for lighter-weight ones, and migratory animals return to their summer homes. As in all biological communities, the food chain here consists of predatory, carnivorous animals and herbivorous animals. Among the predators, almost all of which are nocturnal in their habits, are the red and gray foxes; the raccoons; owls; skunks; and, among the most blood-thirsty of all predators, the weasels and shrews, which require a daily quantity

3a



3b



of meat about equal to their body weight. At the other extreme are the herbivores: deer, hares, marmots, and the numerous varieties of rodents that live in the trees, such as the squirrels and the North American chipmunks. Because of man's continuous destruction of large areas of temperate forests, many of these animals have learned to raid the open lands culti-

vated by man. Foxes, for example, hunt in the open at night and do not disdain garbage from farm kitchens; by day they withdraw into the woods. The raccoons come out at dusk and find an abundance of food, consisting of mice and frogs, in the fields and along ditches.

Among the birds of the forest are doves, crows, many varieties of wood-

peckers, goldfinches, bluebirds, and scarlet tanagers. These differ considerably in their habits and their summer habitats.

Pools formed by streams are often found in the woods of the temperate regions, and they offer ideal conditions of life to a large number of water-loving creatures—fish, frogs, toads, salamanders, and dense swarms of insects. In North

America the snapping turtles are the largest freshwater tortoises, weighing 12 to 20 kg (about 26 to 44 lb). They live in the mud and lie in wait to snap at whatever animal comes within striking distance; they even bite their closest relatives, the mud turtles and the mossy turtles. Another aquatic reptile is the harmless water snake, an excellent swimmer with nocturnal habits. Also typical of forest streams and pools are leeches,

some gastropods, and some small bivalves that survive during the summer and winter dry spells by burying themselves in the mud to take advantage of the traces of moisture that remain there.

In the long course of geologic eras, animal life has evolved and dispersed into its present distribution patterns. Each species adjusts to its physical environment and to the plants and animals around it. An important trend in eco-

nomic zoology—application of zoology in the interests of human welfare—concerns restoration of the balance of nature, which human activities have upset.

The destruction of any one species may result in a train of undesirable consequences because of the interrelationships of animals, particularly in regard to food cycles, which always involve plants. Elimination of predators such as the mountain lion, for example, permits the



CARNIVORES AND HERBIVORES—The forest, like any other biological environment, has its own food chain. Two typical predators are a young red fox (*Vulpes vulpes*), photographed in its nest (Illustration 3a), and a wolf (*Canis lupus*) (Illustration 3b).

The red fox is the most common fox in Europe, Asia Minor, and northern Africa. Both the fox and the wolf roam at night and hunt small rodents. In packs, the wolf often attacks animals larger than itself.

The marmot (*Marmota marmota*), shown in

Illustration 3c, is a small herbivore and a rodent. It is a favorite prey of the carnivorous animals. The marmot, a hibernating animal, prefers to live at an altitude of between 1,500 and 3,000 m (about 5,000 to 10,000 ft). The boar (*Sus scrofa*), a member of the Suidae family, also is herbivorous. A boar has extremely acute senses of hearing and smell. It is an excellent swimmer and, despite its heavy body, a fast runner, making it a popular beast of the chase. Several young boars are shown in Illustration 3d.

excessive increase of herbivorous animals that are their prey and which they normally keep in check; this results in overgrazing of grasslands and forests.

Man has also interrupted natural patterns by transporting an organism from an area in which it is in balance with

other factors to areas lacking the predators and parasites that keep it under control. Major crop and forest pests and epidemics of disease among humans have resulted from man's transference of organisms either by accident or through ignorance.

SMALL CREATURES OF THE WOODS | curiosities of nature

A pleasant stroll through the woods can reward even a casual observer with an amazing variety of life-forms. All that is really needed is a pair of alert eyes, with perhaps a magnifying glass or a hand lens to enable closer observation of the minute features of insects or other small animals of the wood. With a little experience, dozens of different species can be discovered on leaves and twigs and along the ground.

INSECT OR TWIG?

At first these small animals are not so readily seen as birds or mammals, but they are much more numerous. Some insects are difficult to see because they mimic some object in their environment. Good examples of these are the walking sticks, among which one of the commonest is *Diapheromera femorata*. Its slender body, which resembles a twig in size, shape, and color, is about 70 to 100 mm (about 2.75 to 4 in.) long. This slow-moving insect often remains stationary, especially when disturbed, and is therefore extremely difficult to distinguish from a common twig. Leaves of locust, oak, wild cherry, walnut, and hickory are its favorite food, but it dines on the leaves of other trees as well.

PLANT PESTS

Shriveled-up, half-destroyed leaves, tree trunks, and branches that are twisted and swollen in places—these are common enough features of the woodland scene, and much of the damage is caused by the tiny, prolific insects belonging to the orders Hemiptera (true bugs) and Homoptera (aphids and others).

The true bugs have piercing, sucking mouthparts, with which they damage plants and suck their juices. Several true bugs—including the appropriately named stink bugs—produce secretions that cause unpleasant odors and tastes in order to protect them from their enemies. The homes of young spittlebugs are easily recognized; these tiny creatures secrete large masses of white froth that clings to the stems and leaves of plants. Young



A COLEOPTEROUS INSECT—The photograph shows a cockchafer, a scarablike beetle. The insect's tough forewings cover and protect the rear wings and the abdomen.

A HEMIPTEROUS INSECT—Some bugs have a brightly colored scutellum (part of the covering of the thorax) with perfectly symmetrical decorations (Illustration 2).

spittlebugs are protected by this foam while they feed.

One example of a homopterous insect is the aphid, a tiny insect ranging in length from 0.5 to 7.0 mm (about 0.02 to 0.25 in.). Homoptera have sucking mouthparts. Commonly called plant lice, aphids generally congregate in colonies and attack young branches, leaves, and

even fruit. Any plant attacked by aphids is also likely to be swarming with ants, which are attracted by the sweet substances secreted by the aphids. For their part, the ants protect and help the aphids by carrying them from plant to plant, thus encouraging reproduction and protecting the aphids from their enemies. Some species are even bred in ant nests.

BEETLES

So numerous are the species of beetles (Order Coleoptera) that their number—perhaps as many as 250,000—can only be roughly estimated. One feature they all share, however, is the thick, leathery forewings that cover all (or nearly all) of the abdomen when the animal is at rest.

Ladybird beetles are easily recognized by their orange wings with black spots. These little beetles are useful, for they eat aphids and scale insects that damage many commercially valuable plants.

Fireflies are not flies at all, but beetles. They are most commonly seen on a summer night when they flash their luminescent tail "lanterns." The flashings are signals whereby males and females recognize each other.

Bark beetles are not so conspicuous, for they live under the bark of trees where they may do enough damage to kill the trees. Both adults and larvae live in long, cylindrical galleries that become visible after the bark falls from the host trees.

The dead carcass of an animal may contain the adults and larvae of the carrion beetle, which performs a useful function by consuming the remains of dead animals. Some carrion beetles even bury the bodies of mice and other small animals, which are then consumed underground.

Stag beetles are named for the tremendous mandibles borne by the males. Related to them are the scarab beetles, which include May beetles, June bugs, cockchafers, Japanese beetles, rhinoceros beetles, and dung beetles (which were once worshiped by the ancient Egyptians). The dung beetle, also called the tumblebug, can sometimes be seen rolling a small ball of dung along the ground; the dung is then buried and eaten. Eggs also are laid in dung balls where the larvae find sufficient food.

LEAF DWELLERS

A casual examination of a leaf can reveal any of the stages in the life cycles of butterflies or moths (Order Lepidoptera). Most of the eggs open within a few days, and some only a few hours after being laid. They may be isolated or in groups, but they are always laid where the resulting larvae will have easy access to an essential food supply. The eggs almost always have a tough shell, which may be smooth or variously em-



3



4



5

CATERPILLAR—Some persons find caterpillars repulsive, but many of these small animals are attractive. Their colors, their bristles, and their well-coordinated movements make them worthy of attention (Illustration 3).

HORNET—The large head and large compound eyes of this hornet are well in evidence (Illustration 4).

SPIDER—This spider and its web are seen from underneath in Illustration 5. The eight legs are attached to the cephalothorax (fused head and thorax).

EARTHWORM—Earthworms live underground. Their bodies are divided into segments, and each segment has eight small bristles, or setae, that help to anchor the worm to the ground (Illustration 6).

7

A TREE TRUNK ATTACKED BY INSECTS—The photograph shows a small hemipterous insect in the act of digging into a tree trunk. The resulting damage to trees, branches, and leaves is considerable (Illustration 7).

6



8b



LUCANUS CERVUS—The stag beetle (Illustration 8a) takes its name from the fact that the male has well-developed, branched mandibles resembling the antlers of a stag. Groups of eggs or transparent, fragile larvae (Illustration 8b) are easy to find on leaves. Shape and color vary greatly.



8a



or stick-shaped, their coloring also varies widely, changing from a greenish color immediately after being laid to a brownish-yellow or reddish color.

Caterpillars—the larvae of the Lepidoptera—are insatiable leaf eaters. Cylindrical and soft, their bodies are divided into a head of five or six fused segments, a thorax of three segments, and an abdomen of about ten segments. The abdomen bears the three pairs of jointed legs characteristic of insects (the legs on the abdominal segments are not jointed). The head has six simple eyes. These larvae have a characteristic method of locomotion: in most cases they first stretch out their thoracic segments, something like an accordion; next they plant their forefeet firmly on the ground and pull the remaining thoracic feet and the abdominal feet after them. The process is then repeated. Generally considered distasteful creatures, caterpillars nevertheless have elements of beauty, and some possess rather ornate decorations.

The pupal stage of butterflies is a hard case called a chrysalis; that of moths is a cocoon formed of silk threads spun by the larva. Chrysalises and cocoons often can be found in the winter on trees and on other plants. Here the pupae spend the cold months and gradually change into adults that emerge in the spring.

SOCIAL INSECTS

Wasps, hornets, bees, and ants (Order Hymenoptera) often have highly complex social organizations. The members live in colonies and divide the duties of community life among them. The industry of ants may easily be observed by disturbing a small portion of one of their colonies.

Only a few of the many insects that might be sought on a field trip are mentioned above. Flies and mosquitoes often make their presence known; grasshoppers, crickets, lice, and fleas are others that might be seen. Nor are insects the only creatures to be observed: spiders, centipedes, millipedes, earthworms, snails, and slugs command attention.

TROPICAL FORESTS | a lush garden

Several million years ago, when the Earth was not yet gripped by the cold of the Ice Age, perpetual summer reigned over the land surface. Vegetation, resembling that of the tropical regions today, covered the land. With the advent of the glaciers, the primitive tropical forest gradually withdrew into the equatorial regions, where it now exists only slightly altered.

THE TROPICAL RAIN FOREST

Wherever the temperature rarely or never goes below 25°C (77°F), and where the annual rainfall exceeds 2,000 mm (about 79 in.) and is distributed rather evenly throughout the year, the natural vegetation is a tropical rain forest. Because of the heat and the rainfall, the humidity is always high; the atmosphere resembles that of a steamy hot-house. The trees are broad-leaved and evergreen, and there is little seasonal change. Three large areas of tropical rain forest exist today: the Amazon Basin in South America, central and part of western Africa, and the Malay Peninsula and the East Indies. Smaller areas are scattered elsewhere between the Tropic of Capricorn and the Tropic of Cancer (between latitudes 23°30' S and 23°30' N).

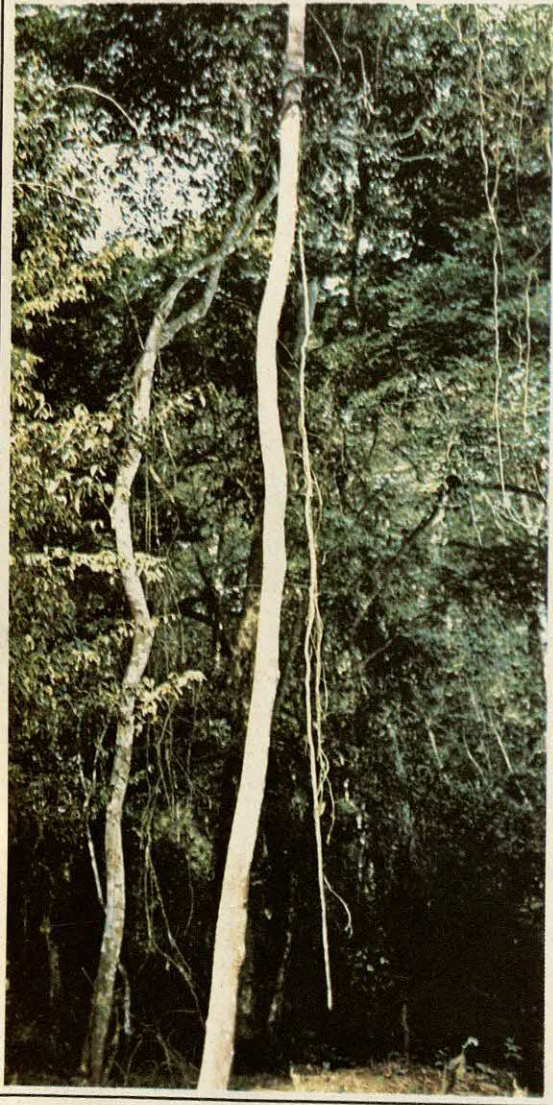
Contrary to popular belief, the tropical rain forest is not an impenetrable jungle with a thick undergrowth of grasses, bushes, climbing plants, and masses of decaying vegetation. Instead, the crown of the trees forms an impenetrable vault overhead that prevents the entrance of sunlight; in the dark shade of the forest floor few plants can grow. The tropical rain forest has been compared with a great Gothic cathedral, characterized by dark, spacious aisles and supported by huge, straight trunks uninterrupted by branches. The ground is often bare or covered with a thin layer of leaves that fall in a sparse shower all year long. Because of the heat and humidity, fallen leaves and branches are quickly decayed by bacteria and fungi if they are not first consumed by insects



THE TROPICAL FOREST—This type of vegetation, common to an area between the equator and the tropics, grows in a moist, hot climate. The foliage of the trees, which grow to great heights and sometimes attain enormous

dimensions, forms an impenetrable vault barring the passage of sunlight. The undergrowth generally is not dense, but it may be thick where a fallen tree or a lightning bolt has opened a path for the sun's rays.

THE FOREST'S INTERIOR—The trees in an African tropical forest have no branches on their lower trunks but have very thick ones at the top. Lianas climb on these trees, forming an intricate tangle in their endless search for the sun.



or other animals. Growth is rapid; a bamboo shoot, for example, may grow 350 mm (about 14 in.) per day.

Trees are the dominant vegetation of the tropical rain forest. The plants that are modest herbs or shrubs in colder regions grow here to imposing dimensions. The myrtles, for example, have stems that are 20 cm (about 8 in.) in diameter; rose plants grow to as much as 6 m (about 20 ft) in height; and violets are 5 m (about 16 ft) tall. The leaves of the trees are broad, leathery, and intensely green. The average height of the taller trees is over 40 m (about 130 ft), and

some trees reach more than 70 m (about 230 ft); from these hang festoons of strong lianas (woody vines). Although the rain forest may appear uniform and monotonous, close observation reveals an unequaled variety of native plants, flowers, and animals. In 5,000 sq m (about 1.25 acres) of forest in the Temperate Zone, there may be 10 or 15 species of trees and sometimes only one or two; but in one sample of tropical forest this size, 141 tree species were found.

Although the trees of the tropical rain forest comprise a great many species, they have similarities such as their leath-

STRANGLER FIG—This epiphytic plant grows on the trunks and branches of tropical trees and puts its roots down along the tree trunk and into the ground. These roots are often so thick and intermingled that they completely cover the trunk of the host tree.



TANGLED MANGROVE—Mangrove trees grow along the watercourses, seacoasts, and brackish lagoons of the tropical zones. Their roots spring outward from the trunk and look like deformed stilts. These roots support the plant, and some of their branches absorb oxygen.



GIANT FIG—This Asiatic tree has a huge main trunk. Its branches slope down to the ground, where they root and form a tangle of secondary trunks surrounding the main one. In time, one tree may come to resemble a thicket.



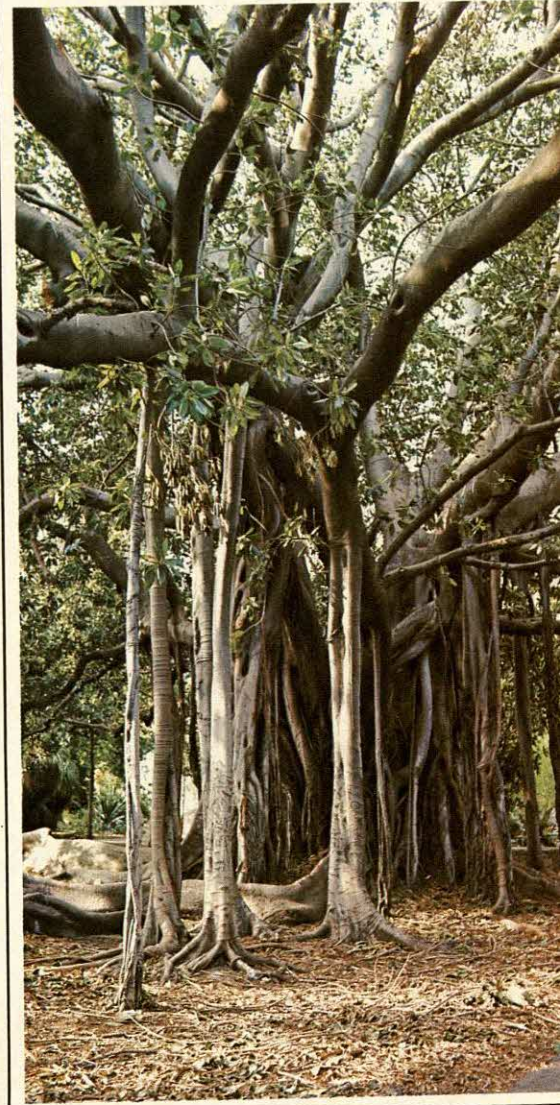
ery leaves and the coarse texture of their bark. The great variety of flowering plants in the tropics has led botanists to conclude that the tropics are the original home of flowering plants. It is believed that they first evolved here and then spread to the temperate zones, where some new species evolved.

The tropical rain forest is stratified into five layers. The crowns of the lowest trees form the dense canopy that shades the forest floor; these trees may reach heights of 6 to 9 m (about 20 to 30 ft). Above them is a discontinuous stratum of tree crowns about 20 m (about 66 ft) above the forest floor. A still higher stratum consists of the crowns of occasional giant trees that reach heights of 35 m (about 115 ft) or more. Below the canopy formed by the crowns of the lowest trees is a sparse stratum of shrubs and young trees, and at ground level are herbs. These strata and the areas between them are the homes of thousands of species of animals; some live their entire lives in only one stratum and never walk on the ground.

Lianas, giant woody vines that may have trunks more than 150 m (about 500 ft) long, are rooted in the ground and grow upward on the trees, lying on their branches and competing with them for light.

Epiphytes are plants that grow on other plants rather than having roots on the ground. Orchids, bromeliads, and cacti are among the flowering epiphytic plants that live in the tropics. Their roots anchor them to the branches of trees and absorb the water and minerals that accumulate in the crevices of bark. Bromeliads have curved leaves that hold reservoirs of rainwater, in which microorganisms and small insects often live.

AERIAL ROOTS—Aerial roots are characteristic of huge tropical fig trees, like this specimen of *Ficus magnolioides*. These roots, which descend from the branches and bury themselves in the ground, look like huge props. In some species the roots are flat or tabular.



BAMBOO FOREST—Bamboo is typical of the tropical regions of Asia. Some species reach a height of as much as 30 m (about 100 ft). Bamboo grows singly, in clusters, or in dense, impenetrable groves. It flowers irregularly, sometimes at ten-year intervals.



When they die and decay, they contribute minerals to the plant. Orchids have roots with an external spongy tissue capable of absorbing rainwater quickly. Because epiphytes have chlorophyll and manufacture their own food, they are not parasitic on their hosts, but they may cause damage by shading them and depriving them of the sunlight they need for normal growth.

Along riverbanks, in clearings created by man or by storm, and in other places that sunlight reaches, the growth of plants is luxuriant. These are the areas of tangled, impenetrable vegetation popularly known as jungle. Growth may be so vigorous that trees on the two banks of a narrow stream may meet above, forming a tunnel through which the stream then flows. Early explorers, who traveled mostly along the rivers, brought back with them the erroneous but persistent idea that the tropical forests are impenetrable jungles.

THE TROPICAL DECIDUOUS FOREST

Where conditions are much like those in the tropical rain forest but where the rainfall is distributed unequally throughout the year, wet and dry seasons occur. If the rainfall during the dry season is less than 50 mm (about 2 in.) per month, a tropical deciduous forest occupies the area. Deciduous plants are those that shed leaves at one time of year. In tropical deciduous forests, the trees drop their leaves during the dry season, and new ones sprout when the next rainy season begins. The dry season of such forests

LIANAS—Lianas are woody vines that grow to high levels, where they reach the light and flower above the foliage of the trees. Sometimes they are thick enough to suffocate the plants to which they attach themselves.



BEAUTIFUL EPIPHYTE—Ferns, mosses, and flowering plants such as this wild orchid in an Indian forest, grow in the forks of large branches or among the tangles of lianas where decayed materials accumulate.



is dry only in relation to the wetter season; in many parts of the world 50 mm of rain a month would be considered very wet. Tropical deciduous forests cover much of India and lie immediately to the north and south of the tropical rain forests in South America and Africa.

There is no sharp line of demarcation between the tropical and subtropical zones. Many tropical plants can be cultivated in the subtropics, and many subtropical or even temperate plants can be grown in the tropics, especially at high altitudes; for elevation (the higher, the cooler) as well as rainfall and the length of the day helps to determine the type of vegetation that will grow in a given zone.

HAYARUM—This is the Indian name of the plant known as the royal poinciana, *Delonix regia*, a native of Madagascar. The plant which bears clusters of red flowers, may grow to 12 to 15 m (about 40 to 50 ft) in height and to 1 m (about 3 ft) in diameter.



TREE FERNS IN THE ANTILLES—Daily rainfall, warm temperature, and an abundance of nutrients cause many species that are small

in other parts of the world to grow enormous in the Antilles. This is the case of the tree ferns, typical plants of forest undergrowth.

CLIMATE AND ALTITUDE |

determining factors



The climate, in general, becomes colder with increasing latitude, or distance, from the equator. Geographical position, however, is only one of the factors that influence climate. Height above sea level has an effect similar to that of latitude, the climate becoming colder with increasing height. The effect of latitude on climate can be observed firsthand by taking a long, and probably expensive, trip that crosses many lines of latitude. A relatively short trip up a mountain, however, reveals climatic changes. A tall mountain near the equator, for example, may have a tropical climate near the base and a polar climate at the top.

The chief effect of altitude on climate is a decrease in temperature; but humidity, rainfall, and wind also vary with altitude, and these factors are further complicated by seasonal variations. All these factors have their effects on plants, many of which are confined to certain altitudes because they can survive only in certain climates.

Although climatologists study a given climate by making a series of meteorological observations over a long period of time, a fairly accurate analysis of the climate of a given locality can be made by observing the type of vegetation that grows in that area, for plant life is a sensitive indicator of climate. A successful climatology field trip can be made with knowledge of the plants characteristic of various climates. A thermometer, an altimeter (or a good relief map), and a hygrometer are useful but not necessary.

The examples illustrated in this article are taken from Italy, an ideal country for observing a wide range of climates. Carefully chosen locations and seasons of the year—the slopes of Mount Etna in summer, for example, and the peak of Mont Blanc in winter—may provide a variation in temperature of as much as 80°C (144°F). Similar variations exist in any country that has mountains at least 1,000 m (about 3,300 ft) above sea level.



SUMMER LANDSCAPE AT LOW ALTITUDES

—Summer in southern Italy is a relatively dry season. By the end of August, large areas of countryside have turned yellow, their vegetation scorched by the sun and lack of moisture. Moving northward, however, the countryside gradually changes color. Vegetation in the foothills of the Alps is green and luxuriant.

At the end of August, in the low-lying Po River valley in northern Italy, trees and plants are covered with leaves and show no signs of the coming fall, as shown in Illustration 1. The winters there are fairly severe, but growing near Lake Garda are palms, olives, and citrus trees, plants usually found only in southern Italy.

WOODS AT 500 M (ABOUT 1,600 FT)—The woodland at a height of 500 m is markedly different from the woodland on the plain (Illustration 2). At a height of 500 m, the air temperature is a few degrees below that of the plain. Here are chestnut woods and relatively thick undergrowth. Occasional beech trees, which are more typical of higher altitudes, may be present. Oaks are also found at this height; but this valuable species is dying out, for these

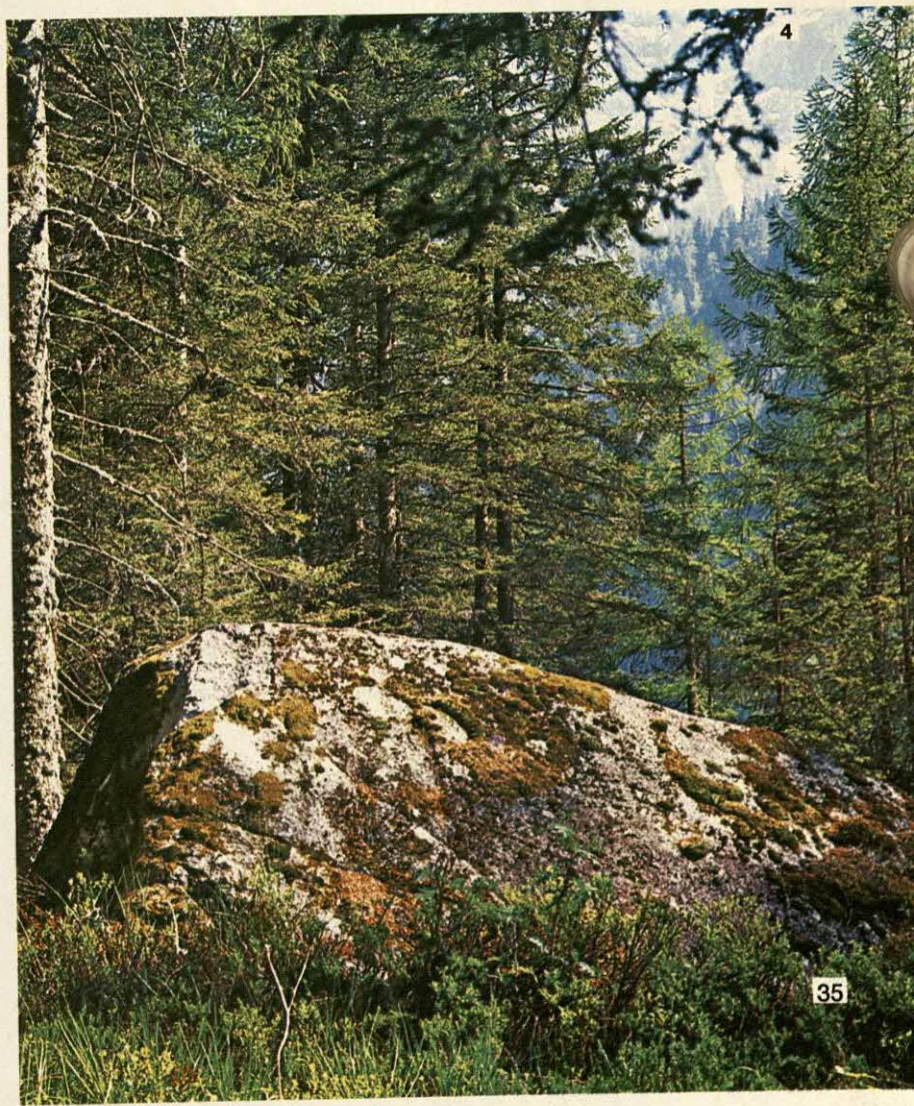
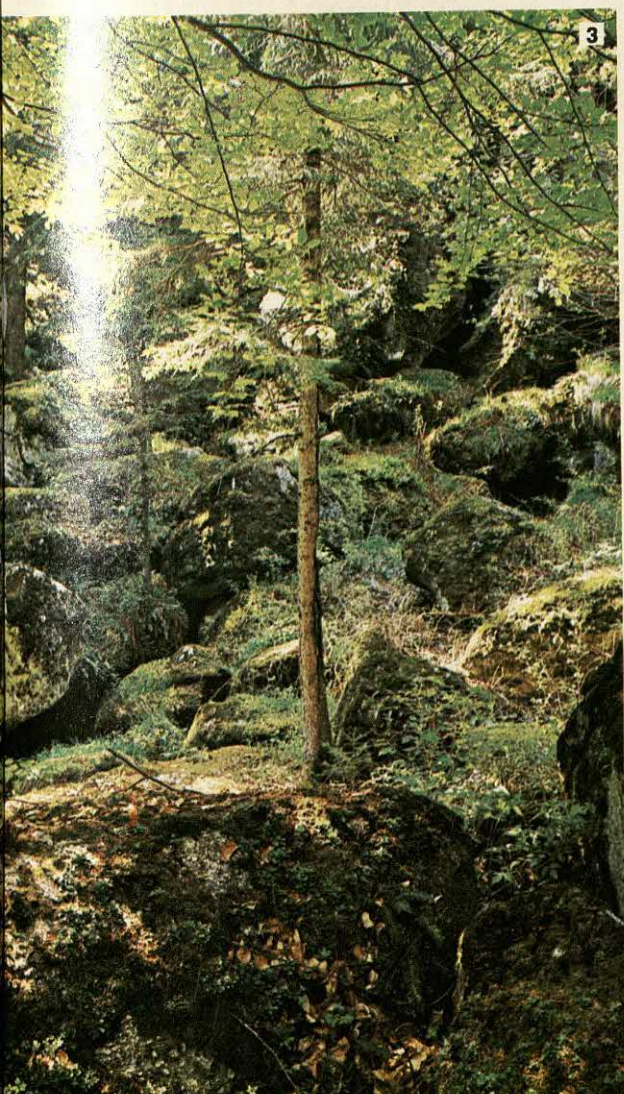
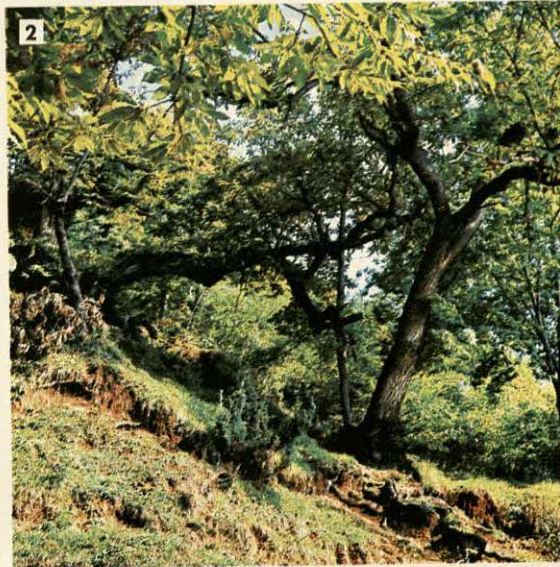
slow-growing trees are being cut down more rapidly than they can replace themselves.

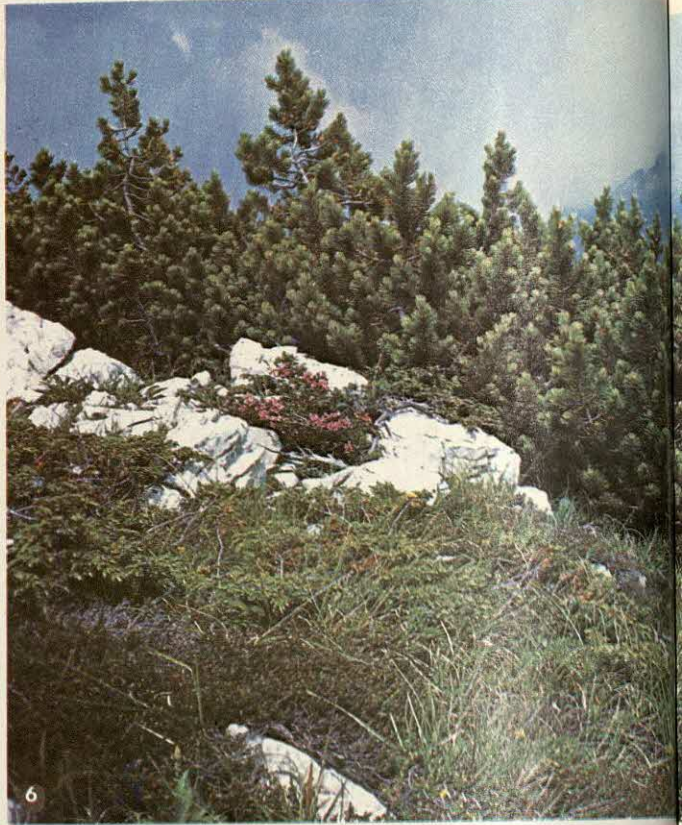
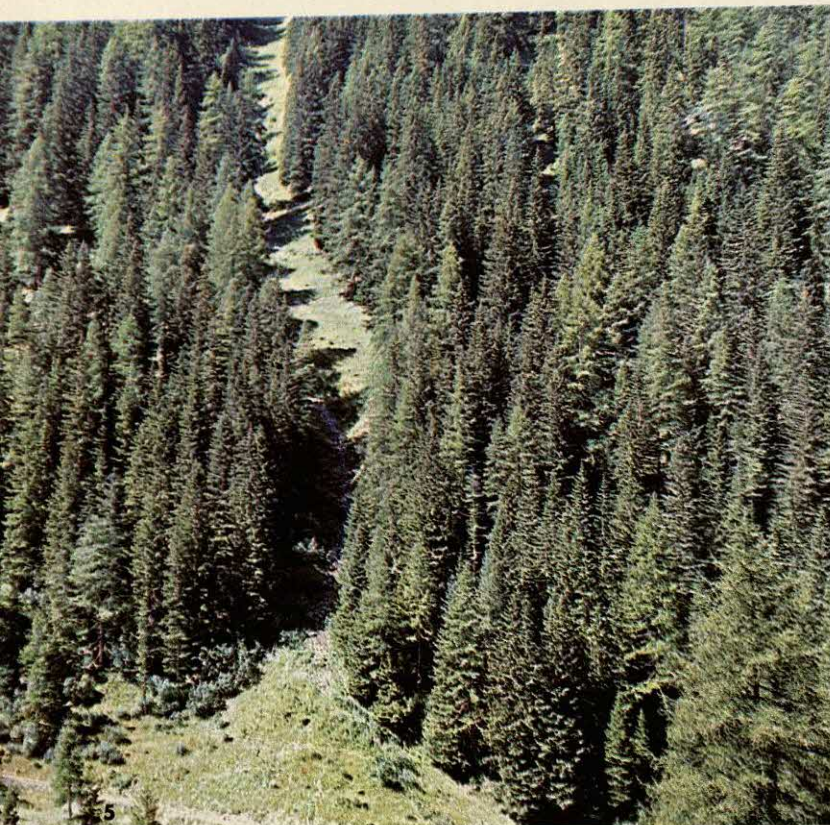
500 TO 1,000 M (ABOUT 1,600 TO 3,300 FT)

—In summer, a climb from the plain to a height of 1,000 m brings a marked drop in temperature, due to a decrease in humidity.

At this height in Italy the characteristic vegetation is the beech, which is found at lower altitudes farther north in central Europe—in Belgium, the Ardennes, and parts of Germany. As a general rule, a change of 700 to 1,000 m (about 2,300 to 3,300 ft) in altitude is equivalent to a change of about 10° in latitude (Illustration 3).

1,500 M (ABOUT 4,900 FT)—At 1,500 m, the lower limit of the coniferous trees begins. With the exception of a few birch trees, conifers are the dominant trees of the Alps. Coniferous woodland (Illustration 4) is typical of central and northern Europe and much of Scandinavia. At 1,500 m the temperature may be 6°C (about 43°F) lower than it is in the plain of the Po River.





2,000 M (ABOUT 6,600 FT)—At this altitude in northern Italy, the woodland scene undergoes a decisive change; the natural vegetation consists almost exclusively of coniferous forests (Illustration 5). Some of the area is used as pastureland. From this point, the number of trees and the amount of undergrowth decrease as altitude increases.

LIMITS OF THE CONIFEROUS FOREST—At 2,500 m (about 8,200 ft), the forest begins to disappear. The temperature is at least 12°C (about 22°F) below that of the plain and may be as much as 15°C (27°F) below. Both temperature and wind contribute to more sparse vegetation. The plants at the upper limit of the coniferous forest never reach the same degree of development as those found at lower altitudes. Often isolated and unprotected from the elements, trees and plants are distorted by the wind, which often blows at high velocities (Illustration 6). Much of the annual precipitation is snow.

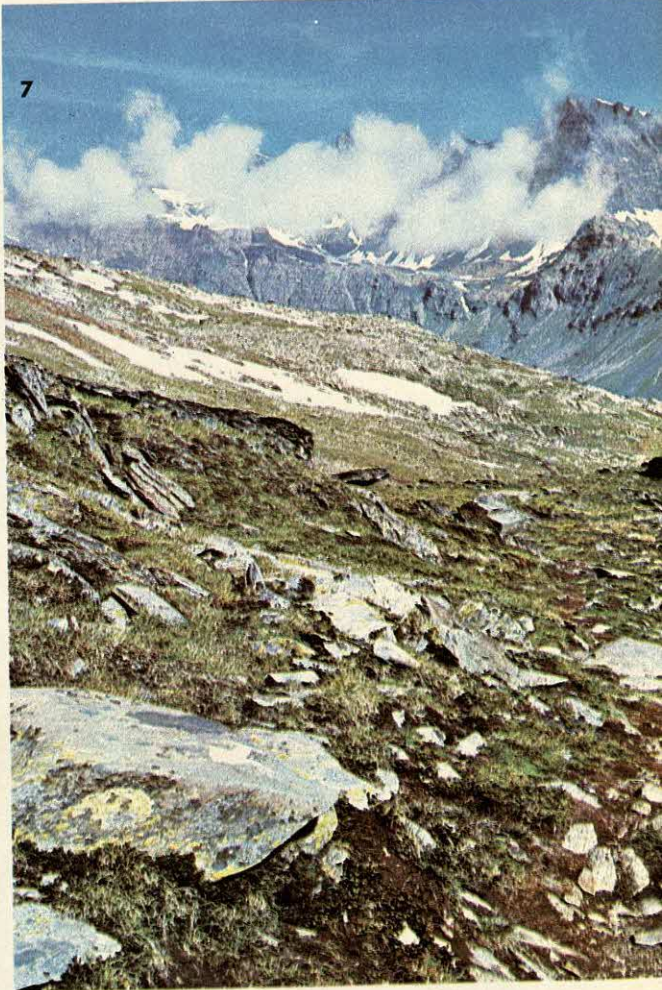
WHERE THE TUNDRA BEGINS—Above 2,500 m (about 8,200 ft) the vegetation consists of tundra plants. These include short grasses, lichens, and peat moss—plants that can survive and reproduce in the brief Alpine summer. The temperature, at least 15°C (27°F) below that of the plain, sometimes drops below freezing at night (Illustration 7).

IN THE SHADOW OF THE HIGHEST PEAKS—At extremely high altitudes in the Alps, the climate often resembles that of the polar regions. At 4,000 m (about 13,000 ft), the temperature may be 20°C (36°F) lower than at sea level; at 5,000 m (about 16,000 ft), it may be 25°C (45°F) lower than at sea level; and in exceptional meteorological conditions, the temperature may drop even lower. The abrasive action of ice and the depth of snow high in the mountains prevent the growth of plants. The mountains are bare, exposed rock (Illustration 8). Birds and mammals are migratory or depend on the sea for food supply.

OTHER CLIMATIC FACTORS—Mountain climbers and pilots know that at high altitudes the air is thin and transparent and the sky is a deeper blue than at sea level. Even on clear days the air at high altitudes contains minute water droplets and dust; however, fewer impurities are present than at sea level, and for this reason the sky appears clearer at high altitudes than in lowlands.

At the low altitudes of the plain (Illustration 9b), the particles act as a kind of shield reflecting back to Earth the heat (infrared radiation) that reaches the Earth from the sun and is radiated from the ground at night. This trapping of heat near the ground keeps temperatures high at low altitudes. The clear atmosphere of high altitudes, on the other hand (Illustration 9a), allows this radiation to pass through it, resulting in low temperatures during the day and sharp drops in temperature at night. The difference between day temperatures and night temperatures is greatest at high altitudes.





BIRDS AND THEIR PLUMAGE | some colorful examples

One of the features that distinguishes birds from all other animals is their covering of feathers. Feathers are necessary for the flight of birds and provide insulation in cold weather. The colors of the feathers make it easier for some birds to hide from their enemies. In some species, coloration permits identification of the sexes. It is usually the male that has the more colorful and

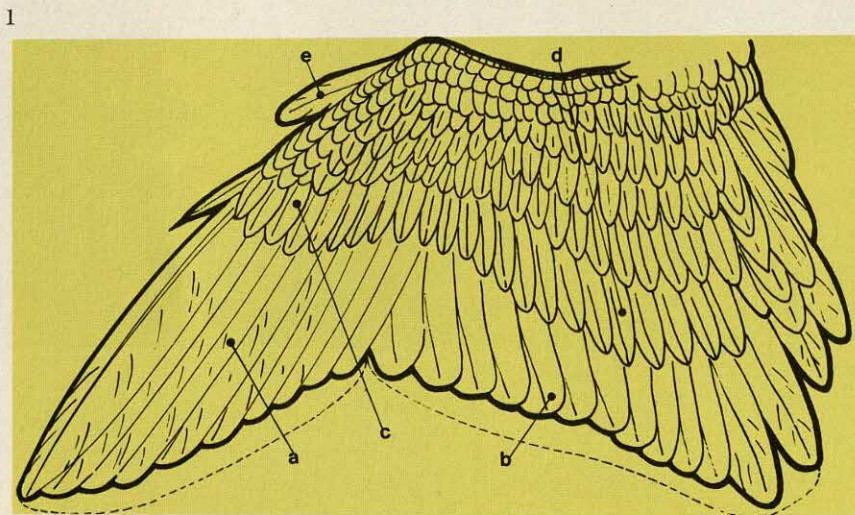
A feather collector should know the date of the breeding season. In southern Europe, where the mating season coincides with spring or early summer, the best months for feather collecting are August and September, or early October in the case of mountain birds. It is also important to know the habitat of the species one is interested in and where it goes in search of food. The easiest

vegetation. In the same places, the dark-streaked feathers of the male gray partridge may also be found. The feathers of this ground bird are little more than 30 cm (about 12 in.) long.

In late summer, the delicate feathers of the wood pigeon and turtle dove may be found among the stubble in wheat fields, where these birds feed on grain and small invertebrates.

Several common members of the woodpecker family, such as the green and the greater spotted woodpeckers, have their habitat in wooded areas in the hills or the plain and in coniferous forests. Their rather small, brightly colored feathers can often be found in elm woods. Easier to find are the feathers of the hooded crow, a bird about half a meter (about 20 in.) long that commonly lives in flocks in country and hill areas.

Both the great blue heron, which has soft gray plumage with black and white patches, and the little egret, with its pure white feathers, normally frequent marshy areas, the banks of streams covered with thick vegetation, and the edges of rice fields. Here they find large



DISTRIBUTION OF WING FEATHERS—The feathers of a bird's wing are divided into **a** primaries, **b** secondaries, **c** primary coverts, and **d** secondary coverts. A small group of rather short feathers makes up the alula **e**, or bastard wing.

variegated plumage, which he uses to attract a mate.

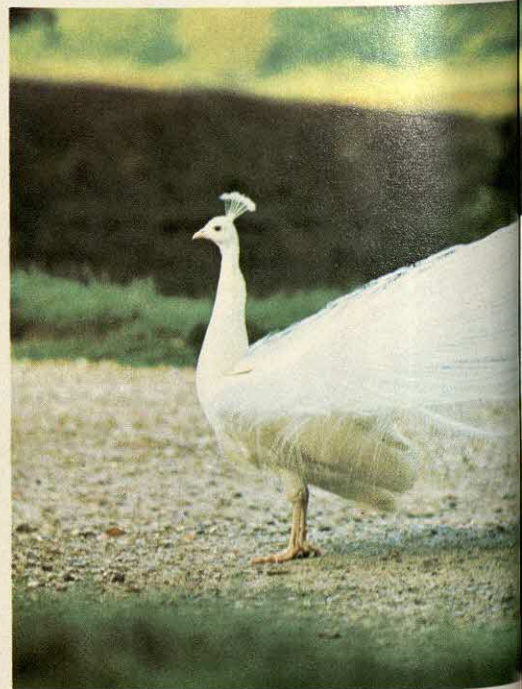
The best time of the year to make a collection of bird feathers is undoubtedly molting time, when a bird's feathers fall out and are replaced by new ones produced by the basal papillae. The molting and refeathering process is done in stages; the first feathers to fall are usually the wing feathers and the last are those on the neck and head. The duration of the molting time varies; it may be a few days, as in the case of some of the Passeriformes (perching birds), or several months, as in the case of the Falconiformes (hawklike birds). In some species, molting takes place only once a year in summer, after breeding. Other birds molt also before the mating season, when the male puts on his richly colored, ornamental breeding plumage.

feathers to find, because they are the biggest and easiest to spot, are the remiges (wing feathers) and the rectrices (tail feathers).

Skylarks are found in fields and uncultivated stretches of plain or hill country where the birds search for seeds and insects, but their feathers are small and the same color as the soil. Their remiges are easiest to spot because they have white edges and are about 8 cm (about 3 in.) long.

The easiest feathers to find are those of the common pheasant, especially the male's rectrices, which are about 45 cm (about 18 in.) long and have characteristic black bands on a gold background. They are often found where these ground birds scratch for their food: in sparse woods in the plain or hills or among clumps of shrubs and herbaceous

2a





THE SPLENDID PLUMAGE OF THE PEACOCK

—No other bird is a match for the peacock in elegance and color of plumage (the female, or peahen, is smaller and rather more modest in appearance). Illustration 2a shows a white

peacock. Illustration 2b shows the majestic bird displaying its magnificent tail feathers with their characteristic peacock's "eyes." Illustration 2c shows another specimen with its train, its black and white striped coverts, and

its deep blue neck and back feathers, and the characteristic metallic sheen on its sides. The peacock's head is crowned with a tuft of fringed, threadlike feathers.





JAY—One of the most common and most brightly colored corvine birds, the jay may reach a maximum of 36 cm (about 14 in.) in

length. Its black and blue barred coverts can easily be found in oak and ilex woods.



LITTLE EGRET—This white heron has a wingspan of more than a meter. The fine feathers on top of its head appear only in the breeding season.

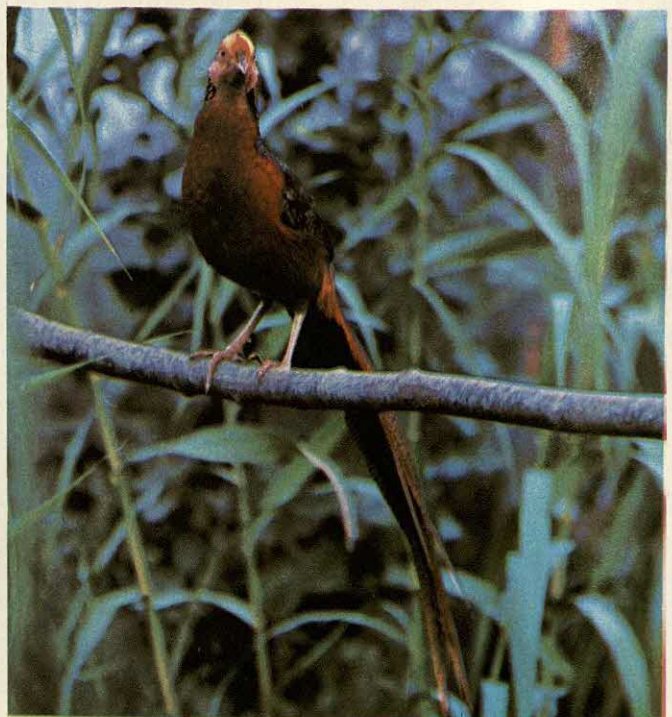
quantities of the fish, frogs, mollusks, and other water animals they feed on. Hunting the plumage of these birds may be difficult because of the birds' habitat.

The male of the mallard, or wild duck, another inhabitant of marshes and other inland waters, has interesting multi-colored feathers in its nuptial plumage. Collecting them is difficult, however, because at molting time mallards lose all

THREE TYPES OF PHEASANT—In many species of pheasant, the males have multicolored plumage while the females are duller in color

and much less eye-catching. Illustration 4a shows a male black grouse, which has shiny, almost black plumage and characteristic wing

feathers folded into the shape of a lyre. Illustration 4b shows a golden pheasant, so called because of the color of its head feathers.



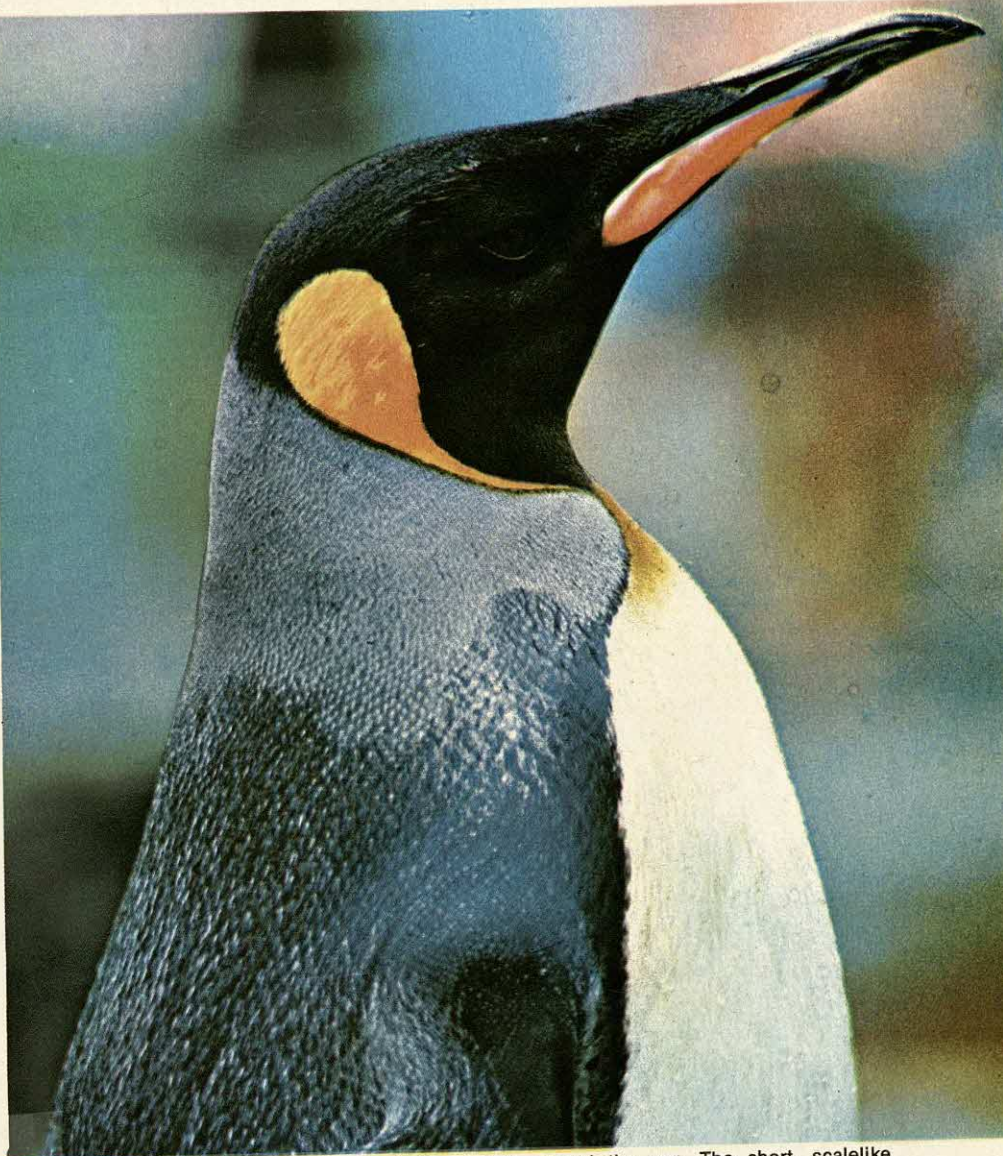


OSTRICH—The ostrich's feathers are limp and soft. The male's body feathers are black, and his wing and tail feathers, white; the female's feathers are uniformly grayish-brown.

their wing feathers simultaneously and so, unable to fly, they hide themselves in thick vegetation.

In open areas in the plain or in mountains below 1,000 m (about 3,280 ft), it is not difficult to find the feathers of the kestrel, a small common hawk with an unmistakable striped coat with dark patches. Finally, a very common bird, the blackbird, which has shiny black

Illustration 4c shows a beautiful silver pheasant, originally from China; this bird may reach 1.10 m (about 3.6 ft) in length.



KING PENGUIN—This species of penguin is gaily colored, with a characteristic yellow patch around the ear. The short, scalelike feathers are rather hard.

feathers, about 12 cm (about 5 in.) long in the tail, is found in city parks and fields.

Feathers can be cleaned and dried with a cloth or a piece of blotting paper and kept in an album. Pins may be used to fasten them to the pages. If the feathers of water birds are covered with grease, they can be cleaned with gasoline. Feathers stained with blood or soil can be cleaned with acetic acid. Mothballs or insecticide spray will protect a feather collection from the ravages of moths.

Long useful to man, feathers provided quills for writing as early as the sixth century. From then until steel pen points

were introduced in the nineteenth century, feathers served as the principal writing implements. Quills from the swan were preferred to those from the goose, but goose quills were used more commonly. Quills from crows were especially desirable for making fine lines. Quills obtained in the spring from living birds proved best for writing, and preference was given to feathers from the left wing, which curved away from the writer.

Feathers have been useful also as stuffing for pillows, quilts, and other bedding; for ornamental purposes; for brushes and dusters, and for the preparation of artificial flies for fishing.



GOLDFINCHES—The cup-shaped nest of the goldfinch is usually built in evergreen trees

and often, particularly in central and southern Italy, in cypresses. It is padded with soft

material, and it holds two sets of eggs and chicks a year.

A bird's nest is the shelter for its eggs and the young birds that hatch from them. A secure nest must be sturdy and either out of the reach of predators, camouflaged, or hidden.

In many species (including swallows, woodpeckers, and kingfishers), male and female birds contribute about equally to the making of the nest. Hummingbird and ovenbird nests are made entirely by females, and shrike nests are built only by males. In some species the job is shared unequally by the two sexes.

There are few birds that do not build nests; one of them is the goatsucker or nightjar, a dark-plumaged, nocturnal, insectivorous bird that deposits its eggs, unprotected, on the bare ground, leaving them at the mercy of enemies and the elements. The fairy terns of the Pacific

merely lay their eggs on bare tree branches. During the long Antarctic winters, the Emperor penguin holds its egg on its feet and warms it with the heat from its abdomen. The cuckoo uses the nests of other birds; it lays its eggs in a nest that already contains eggs, and the hosts (any of over 100 species of birds) usually hatch, feed, and bring up the baby cuckoos, often at the expense of their own chicks.

There is a wide variety of shapes and building techniques in use among different species of birds, but there usually is consistency among the nests of birds belonging to the same species. Nest building is instinctive; in some species, birds building their first nests produce perfect structures, but in other species birds make better nests as they gain

experience in the art.

Generally, the more complicated the nest, the higher the bird is in the evolutionary scale—starting with water birds at the bottom and going up to the small Passeriformes (perching birds), whose nest building reaches a high level of artistry. Sea birds limit themselves to piling up a few stones or blades of grass that house the eggs they lay. Further up the evolutionary scale, the nests of large birds, such as the birds of prey and the herons, are usually formed of thick branches intertwined on a tree or in a hole in a rocky cliff out of range of an attacking enemy. In the more highly evolved species, the nest may take the shape of an open cup, or it may be pouch-shaped or spherical and resting on a support. Many weaverbirds build



ORIOLE—The oriole constructs its nest in the tallest treetops in the junction between two branches. The nest is made of grass stalks, cloth, and down. It hangs free, but it is firmly attached to the branch and has turned-in edges that make it safe for the chicks.

GREAT REED WARBLER—Found typically in marshy areas, the reed warbler's pouch-shaped nest is woven into the reeds with grass and vegetable fibers. It can be pushed up or down the reeds as need be (Illustration 3).

NUTHATCH—This bird builds its nest in holes in trees and often reduces the size of the entrance opening by walling it up with mud. Illustration 4 shows the entrance opening to a nuthatch's nest.

WESTERN LONG-TAILED TITMOUSE—This curious, highly artistic nest has the shape of a roundish sack with a side opening. Made of down, wool, and feathers, it is similar to the penduline titmouse nest in construction, but it is wedged firmly between branches.



BLACK KITE—This nest is a rough structure of strong, dry twigs built in the junction of two or more branches in the tops of tall trees such as poplars and oaks (Illustration 6).

SPOTTED WOODPECKER—This bird shows a preference for thick woods where it builds its nest in holes in tree trunks, usually high off the ground. The bird lays four to seven shiny white eggs that hatch in May (Illustration 7).

spherical pouches with the side entrance extended into a tube that hangs down vertically. The nests that reach the highest level of perfection hang from a support by their edges instead of being wedged between branches or stones. The oriole's nest, for example, is supported on its sides, and the nests of many swallows are attached to vertical walls.

BUILDING MATERIALS

Nests may be constructed of animal, plant, or even mineral substances, and sometimes the range of a given species may be restricted by the extent to which the right materials are available. Most commonly used are plant materials such as branches, roots, and leaves, which the bird interweaves by movements of its beak. Fresh grass or dry grass moistened to make it softer is also used.

Sea gulls use grass and seaweed, which

they pile up into a large heap on the ground. Seaweed is an excellent cementing material because it hardens rapidly when it is removed from the water.

The tailorbird builds its nest chiefly of leaves, stitching the edges of the nest together with plant fibers that it uses as threads. With the point of its beak, the bird punches holes in the edges of one or more leaves, passes the threads through, and knots them firmly. Each stitch is independent of the next. The funnel-shaped nest may be lined with grass, hair, or feathers.

Some hummingbirds and birds that build pendulous nests mix soft plant materials with spider's webs to line and support their nests. The walls of the nest are frequently made with dead leaves, mosses, and lichens. Mosses and lichens fixed to the outer surface camouflage the nest. Building materials of animal origin, often used to line the inside of the nest,





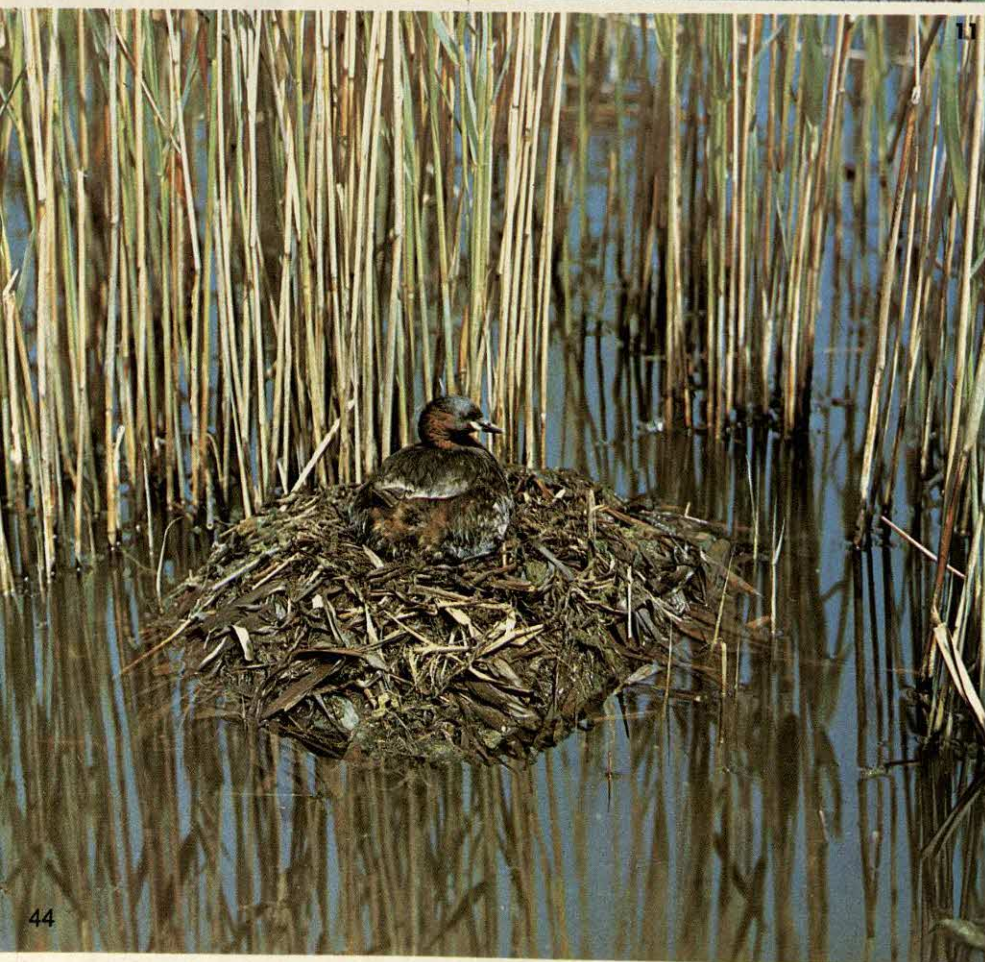
TREE CREEPER—Commonly found in forests of broad-leaved trees, this bird nests in holes in trees. The nest is a rough structure with a simple padding of mosses and blades of grass.

BLACKBIRD'S NEST—This simple structure of grass and roots holds pale green eggs with reddish-brown spots. The eggs are laid two or three times a year between February and May (Illustration 9).

STARLING—The starling nests between April and June in holes in trees, cracks in walls, or old, abandoned woodpecker nests. Certain species of this common bird migrate every year from northern Europe to the coasts of North Africa (Illustration 10).

LITTLE GREBE—Living in marshes or among reeds by the banks of pools, the little grebe has a floating mass of reeds, grass, and leafy branches for its nest (Illustration 11).

PENDULINE TITMOUSE—This bird prefers marshy areas and watercourses, where it skillfully builds its flask-shaped nest. Firmly attached at one end to a branch above the water, the nest is built of closely woven plant fibers and lined with down, feathers, and other soft materials. It has a round, lateral opening.



include wool, feathers, and horsehair. Feathers are sometimes taken from places frequented by birds of prey at molting time; swallows, for example, catch the feathers in the air after raising them by the beating of their wings as they fly past the molting place.

Spider's webs are widely used as a cementing material to insure cohesion between the other materials. Some birds secrete a rather viscous saliva that has the same function. The oriole, for instance, uses its saliva to soften the plant fibers that attach the nest to the branch. The bird's nests used in Oriental cooking

are real nests constructed mostly of the saliva of the salangane, a small swift living in the East Indies.

Another widely used building material is loam, from which most of the nests of blackbirds, magpies, thrushes, and swallows are made. Various other materials and objects are used, including paper, small pieces of cloth and skins shed by snakes.

FINCHES

Curiously bowl-shaped and generally made by the female, the finch's nest is usually built in trees or bushes at various distances from the ground. Materials used include tightly woven twigs and small branches; the outside is covered with mosses and lichens that blend with the surroundings (finches are so good at camouflaging their nests that they are often mistaken for moss- or lichen-covered knots in the tree trunk), and the inside is padded with soft plant materials, feathers, and spider's webs. Accompanied though not helped by the male, the female collects all the necessary materials and then flies off to the chosen site. The only tools the bird has at its disposal are its claws, beak, and belly. It holds the materials to be used in its claws and uses its beak to pull, twist, and weave them. Once this laborious task is accomplished, the bird uses its belly to test the nest and widen it and bring it into the correct shape.

ORIOLES

The oriole (the name derives from the Latin for "golden") is a graceful migratory bird with golden plumage. Its song is heard in parks and gardens as well as woods. The oriole's nest is an artistic construction, generally found in the tallest treetops and lying horizontally in the fork between two branches. It is shaped like a fishing basket. At nesting time, the male and female first wrap long twigs and strips of bark around the fork of two branches and then cover them with copious saliva that binds them into a compact mass. After the structure has been consolidated in this way, the birds add twigs, grass, pieces of bark, cloth, down, and pieces of thread. Caterpillar larvae also are sometimes used as building material. For padding, orioles use woolen threads, feathers, and fine grass.

The nest usually hangs about 5-10 m (about 16 to 33 ft) above the ground and is usually hidden among the foliage, though its characteristic shape makes it easy to recognize. The turned-in edges prevent the eggs, and later the nestlings,

from falling out of the nest.

PENDULINE TITMICE

The penduline titmouse, a small bird similar to the great titmouse, is an expert nest builder. It lives in Italy in the summer, though in winter it migrates to warmer and more hospitable climates. It builds its nest on the banks of lakes, in willow trees or poplars, or hidden among dense canebrakes. The nest, roomy and comfortable and not far above the ground, is shaped like a flask with its upper end attached to the branches. Some titmouse nests have only one opening in the side; others have two, opposite each other and so small that only the tiny titmice themselves can pass through. The nests are built of plant materials that the bird rolls into a ball and covers with its own special kind of sticky secretion; thin plant fibers are used to bind the material together and to fix it firmly to the branch. The color of the nests ranges from white to darker hues depending on the materials used. In some regions of Asia where the penduline titmouse lives, these nests are often used in popular medicine, because they are believed to emit medicinal substances with fever-reducing properties when burned.

NIGHTINGALES

A relatively lightweight structure made of leaves and grass, the nightingale's nest is hidden in undergrowth on the ground or not far above it. The bowl-shaped interior is padded with materials of animal origin.

WRENS

The wren, a tiny bird found in hedgerows and bushes in winter, is one of the smallest birds. Its nest is a roundish structure completely closed except for a relatively wide entrance hole at the side. It is built of moss, grass, and ferns and is usually situated on the ground, under the roots of a tree, in holes in the ground, or in piles of branches. The male is responsible for the framework and outer covering of the nest, and the female looks after the padding inside. The curious thing about wrens is that they have one nest for hatching their eggs and others, unpadded, for resting or playing.

SWALLOWS

Once a swallow has built its nest under a roof, beam, or balcony the nest becomes its permanent home. Every year, when they return from their travels,



SWALLOWS AND WRENS—The swallow usually builds its nest of mud and straw under roofs and balconies (Illustration 13a). The interior is padded with soft material on which the bird lays its eggs. Each spring, when a swallow returns from its travels, it occupies the same nest that it did the year before. If necessary, it rebuilds any damaged parts.

The wren's nest (Illustration 13b) is made of mosses, grass, and ferns. It usually is located at ground level in small holes or among the roots of trees. Wrens typically have more than one nest, each with a different function; the nest where the eggs are to be laid is softly padded on the inside.

swallows occupy the same nests; and when the chicks are grown, they too will come back the following year to renovate their old home, if necessary, and live in it once again. The nests are roundish in shape and thicker on the side where they are secured to the wall; the opening is horizontal. It takes about eight days to prepare the nest for the chicks. The exterior is made chiefly of mud, but the inside is padded with softer material. There are many species of swallows, and each species has its own nest-building technique.

FISH OF THE DEEP | life at great depths

The land surfaces of the Earth have been intensively explored by man. Yet the oceans contain the least known, the least explored, and the darkest regions of the Earth.

The surface of the world's oceans totals 362 million sq km (about 140 million sq mi), slightly more than 70 percent of the entire surface of the planet. The upper part of the ocean is constantly changing; at one moment it is calm, and at another, giant waves are whipped up by the winds. Sunshine, cloudy skies, day and night come and go. But at great depths there is little change from moment to moment, from year to year, or from century to century.

maintaining always close to the freezing point, and free of turbulence. The concentration of oxygen is low, while that of carbon dioxide is relatively high. The pressure is also high, increasing with depth to a maximum of 1,000 times what it is at sea level.

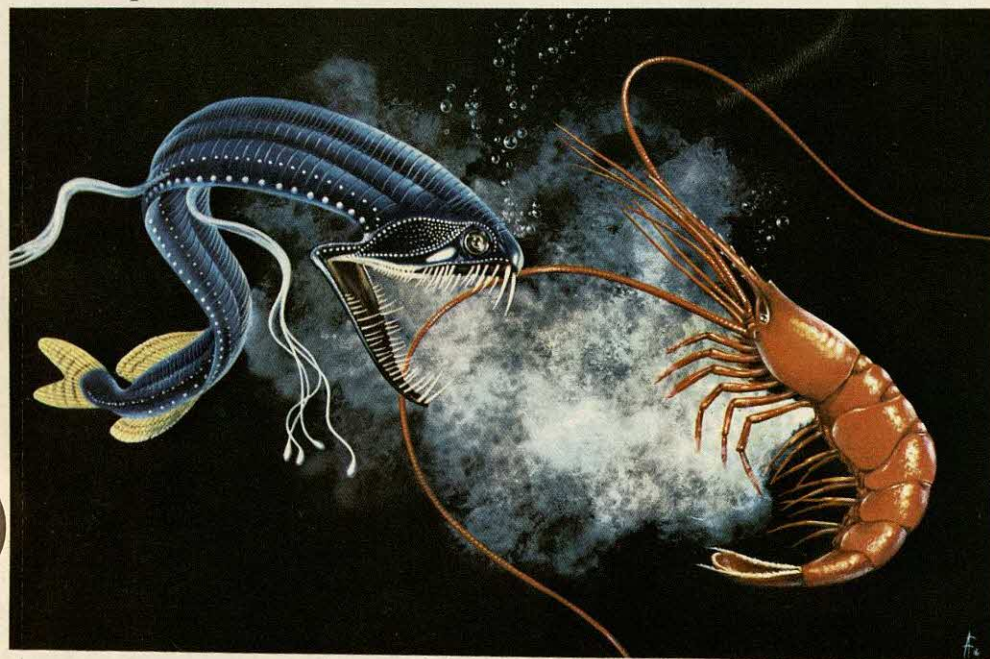
The ocean floor is rocky in some places, while in others it is covered by ooze that is the accumulation of debris that has fallen slowly from above for millions of years. The three types of ooze found in abyssal areas are globigerina, which contains large amounts of the calcareous shells of the protozoan, *Globigerina*; radiolarian ooze, which consists of the siliceous shells of protozoans of the order

are doubtless recently evolved creatures that found less competition in the sparsely populated abyssal zone than above. In their move downward, the organisms underwent several adaptations that allowed them to survive in their new environment.

ADAPTATION TO THE ABYSSAL ENVIRONMENT

When compared with the more familiar fishes of surface waters, many of the abyssal animals appear strange and even grotesque. Many of their unusual proportions are adaptations to life in a world of darkness. Ordinary eyes are of

1



A FIGHT FOR SURVIVAL IN THE WORLD OF SHADOWS—*Photostomias guernei* has an enormous mouth with long, sharp teeth and, like most abyssal fish, is dark in color and luminescent. In the abyssal zone live vividly colored shrimps; when attacked by *Photostomias*, they emit clouds of luminescent material that probably serve to blind and distract their aggressors.

THE KING OF THE HERRINGS—*Regalecus glesne*, the oarfish, is found in all the world's seas, including the Mediterranean. A few specimens have been found dead or dying on beaches. The body is dark blue and silvery with black stripes, and may be 6 m (about 20 ft) long. The fins are bright red. The dorsal fin terminates on the head, forming a gaudy plume, while the ventral fins are long, thin filaments. The name "king of the herrings" was given to *Regalecus* by fishermen, who erroneously believe that it guides the herrings in their periodic migrations (Illustration 2).

SILVERY MIDGET—*Dirotmus argenteus*, about 5 cm (2 in.) long, lives at depths of between 200-500 m (about 700-1,600 ft), just above the abyssal zone (Illustration 3).

THE ABYSSAL ZONE

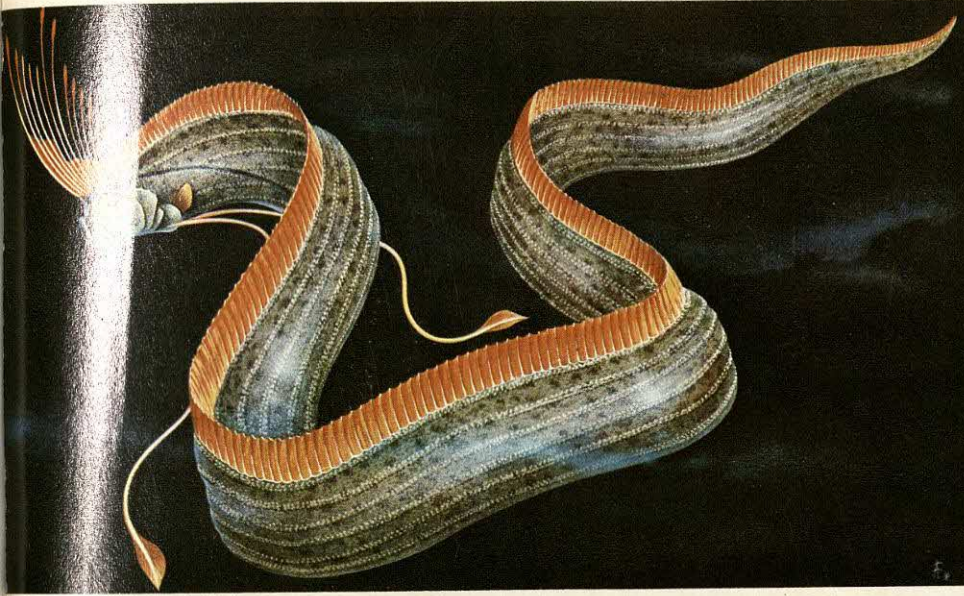
Below a depth of 2,000 m (about 6,600 ft) and extending to the bottoms of the ocean trenches, the deepest of which reaches almost 11,000 m (about 36,000 ft), is a region called the abyssal zone. There, no sunlight penetrates, and organisms live in almost perpetual night, the darkness penetrated only by the feeble light produced by certain of the organisms themselves. The water is cold, re-

Radiolaria; and diatom ooze, which contains the siliceous cell walls of diatoms, some of the most numerous algae in the oceans. These oozes also contain a considerable amount of organic matter that is used as food by some abyssal fauna.

Life was once thought to have first evolved from the abyssal oozes, and the abyssal animals were considered primitive life-forms. But modern theories maintain that life originated in surface waters; most abyssal animals, therefore,

little use in complete darkness or in very dim light; thus some abyssal animals have small eyes or none, while others have evolved huge, sensitive eyes that collect what little light there is.

Some abyssal animals possess luminous organs and make their own light, or carry luminous bacteria in special organs. These biological lanterns, called photophores, are believed to serve several functions. In some species they may act only as headlights, illuminating the way for their



owners; in other species they seem to act as lures, attracting prey. On the head of the anglerfish (Illustration 6) is an outgrowth with a luminescent tip that the fish dangles before its mouth like a baited line. Lights in other species may be recognition signals by which males and females of the same species find each other or by which schools of fish stay together. When attacked, some shrimps emit clouds of luminescent material that is believed to confuse their enemies and give the shrimp an opportunity to escape (Illustration 1). The functions of other luminescent organs are puzzling—especially those that illuminate the internal parts of their owners.

Since plants cannot grow in the blackness of the abyssal zone, the only food must come down from above. When plankton (diatoms and other single-celled algae, protozoa, and the smaller kinds of larvae), which are so abundant in the upper waters, die, they sink to the ocean floor. Similarly, when fish, whales, and other large marine animals die, their bodies sink. It has been estimated that a few days to a few weeks are required for such matter to reach the bottom. During this time it is fed on by fish at all depths. For this reason little reaches the abyss, and abyssal animals are so modified as to take advantage of what food does come their way. Some fish (Illustrations 1, 4, and 5) have unusually

large jaws that enable them to swallow remarkably large prey, and several fish have stomachs that expand to accommodate prey larger than the fish itself (Illustration 7). These fish may feed only rarely, and they digest their prey slowly over long periods of fast, consuming even the scales and bones.

Abyssal animals confined to the bottom feed on the thin rain of dead plants and animals from above. Many of these animals, like sponges, sea lilies, and some mollusks, are permanently attached to rocks. Others, like worms and other mollusks, live in burrows they make in muddy deposits. Starfish, sea urchins, crustaceans, and some worms and mollusks creep over the ocean floor, feeding as they go. Some fish have large mouths with rakelike teeth, through which they sift the mud on the sea bottom, recovering anything edible.

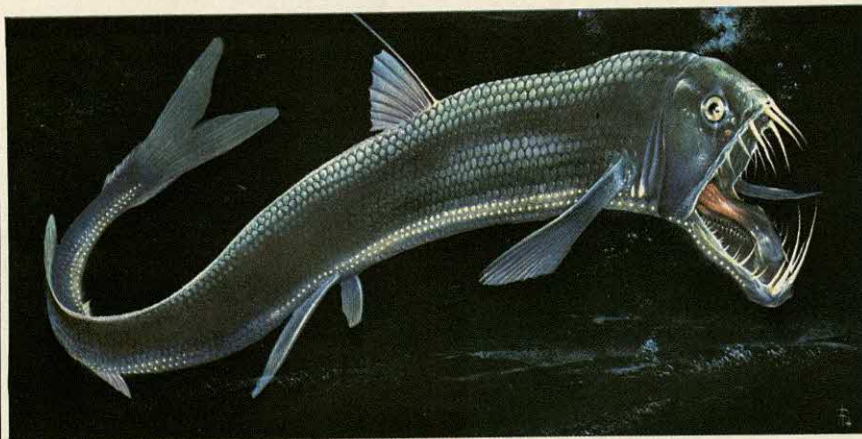
On the basis of their methods of feeding, the animals of the abyss fall into two groups: scavengers, which feed on dead

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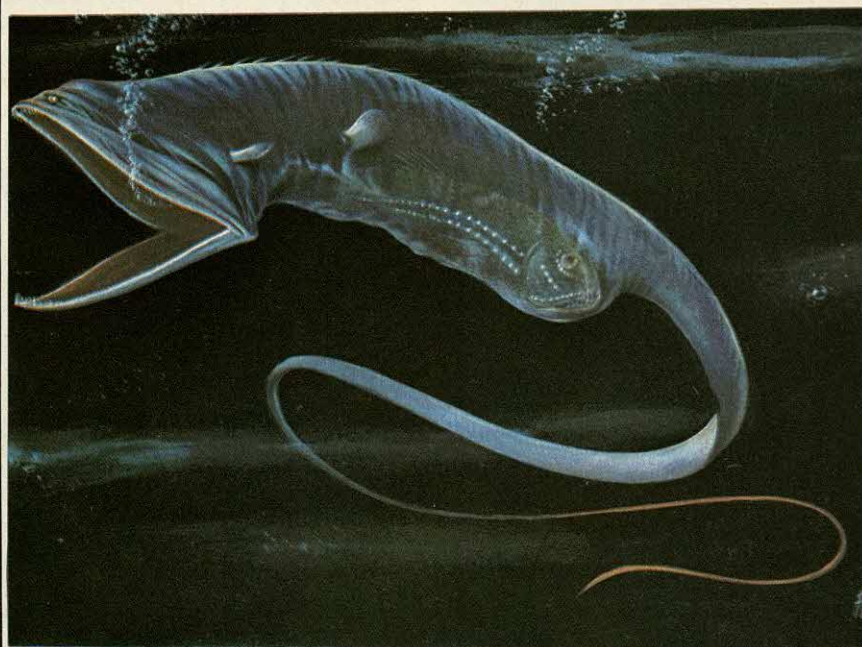


large jaws that enable them to swallow remarkably large prey, and several fish have stomachs that expand to accommodate prey larger than the fish itself (Illustration 7). These fish may feed only rarely, and they digest their prey slowly over long periods of fast, consuming even the scales and bones.

organic debris descending from above or which strain and filter out organic matter that has accumulated on the bottom; and carnivorous animals that eat the



SEA VIPER—*Chauliodus slohanei* has a huge mouth with very long, sharp teeth that protrude when its mouth is closed. It also has rows of photophores in the lower part of its body. The sea viper lives at depths of 500-3,000 m (about 1,600-10,000 ft).



BIG-MOUTHED CARNIVORE—*Saccopharynx ampullaceus* may be as long as 1.5 m (about 5 ft), and can swallow large fish, such as *Chiasmodon niger*; a victim is visible in its stomach. *S. ampullaceus* lives at depths of 1,500-4,000 m (about 5,000-13,000 ft).

ANGLERFISH—*Melanocetus johnsoni* is found in the Atlantic at depths of about 3,000 m (about 10,000 ft). The body is about 10 cm (4 in.) long, and stocky. The mouth is very large, especially in females. On the huge head is a formation terminating in a strange luminous organ that probably attracts prey.

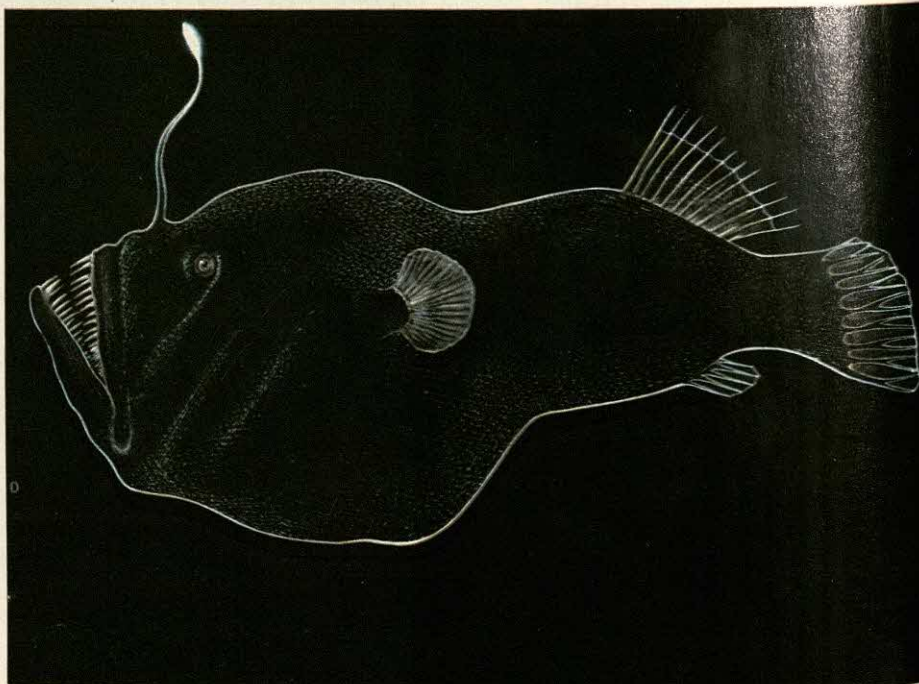
EXPANDABLE PREDATOR—*Chiasmodon niger* has a stomach that dilates to receive victims that are several times larger than itself. It lives at depths of 1,000-3,000 m (about 3,300-10,000 ft) (Illustration 7).

TELESCOPIC EYES—*Opisthoproctus soleatus* is about 10 cm (about 4 in.) long. The fairly massive body has a flat ventral plate resembling that of a sole—hence the name *soleatus*. The mouth is unusually small and toothless, while the large, upturned eyes are telescopic. Specimens have been caught in the Atlantic at depths of 1,000-3,000 m (about 3,300-10,000 ft) (Illustration 8).

scavengers, their carnivorous brothers, or even their own eggs and larvae, or the occasional fish that strays down from above.

The coldness of the abyssal waters seems to be of no disadvantage to the abyssal fauna. It may even have been helpful in slowing down the rate of metabolic activities and thereby reducing the need for food and oxygen, both of which are scarce in the depths.

The high concentration of carbon dioxide in abyssal waters increases the solubility of calcium and reduces its availability to animals for building calcareous skeletons. Partially because of this, some abyssal animals have a remarkably delicate and fragile appearance that is at first all the more surprising when the tremendous pressures of their environment are



considered. But the pressure within abyssal animals is the same as that without, and many abyssal animals require no special skeleton or other protection against pressure.

PHOTOPHORES

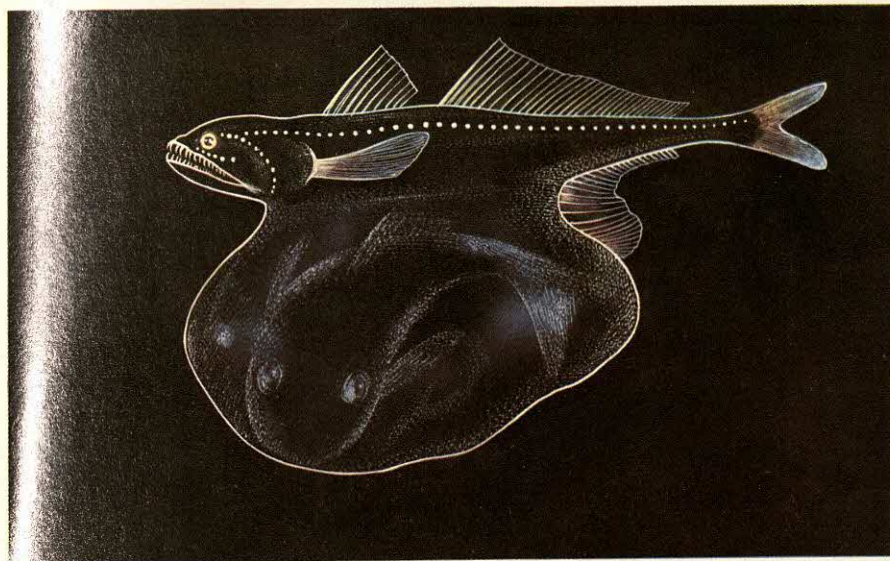
Many of the photophores, or light-emitting organs, of the abyssal fauna resemble man-made lanterns in their gen-

eral construction. The source of light has a concave reflecting surface behind it and a lens before it. The lenses or other tissues through which the light passes may be pigmented; this affects the color of the light emitted by the animal as does a colored lampshade or a stained-glass window.

The light source may be the fish's own tissue, or it may be luminous bacteria that live symbiotically in the photophore where they receive food from their host. *Photoblepharon*, a fish of the East Indies, has two such organs that are continuously lit by their bacteria. Each photophore is equipped with a flap of black tissue resembling an eyelid that the fish draws down over it at will, thus turning the light "off".

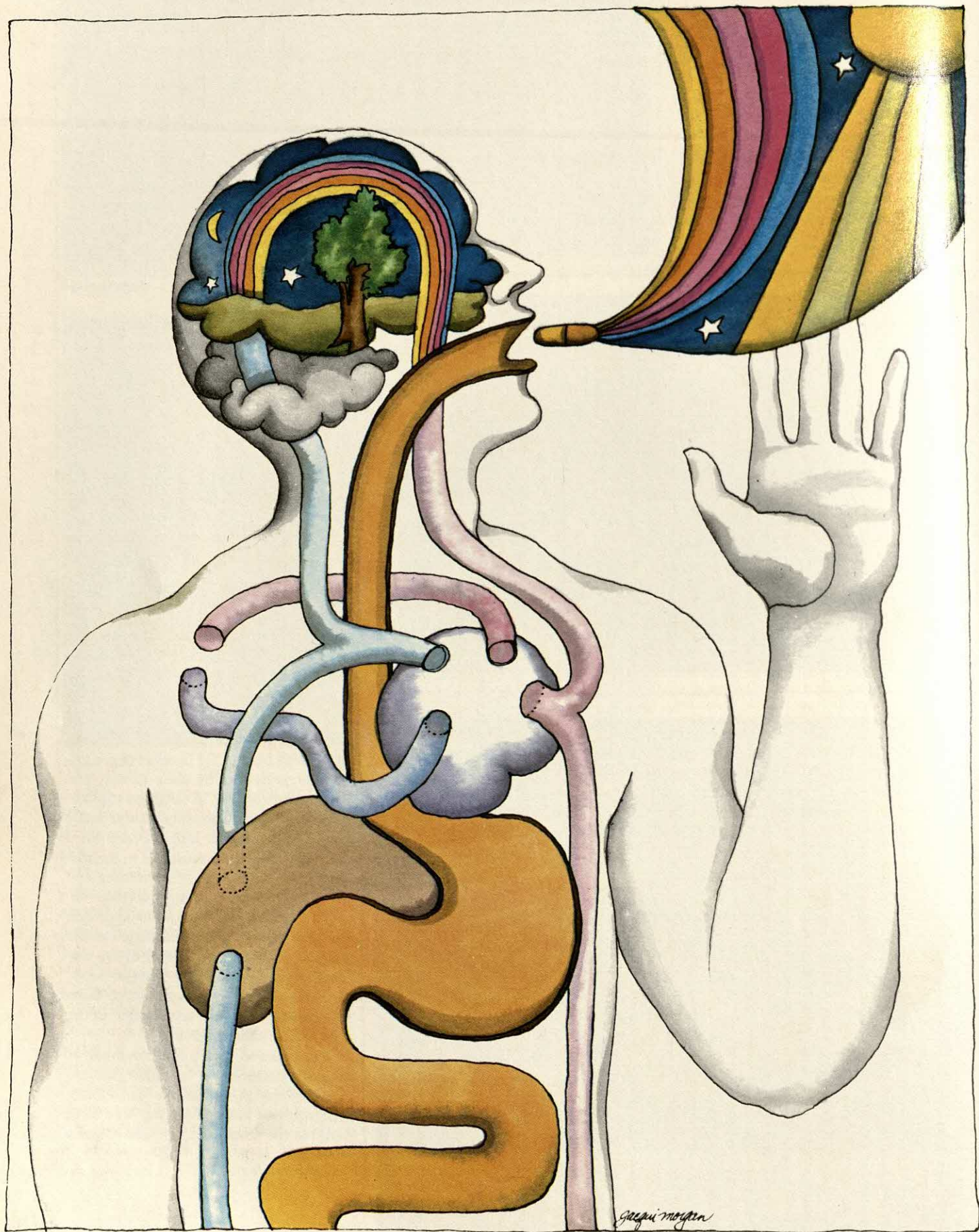
The largest-known abyssal fish is *Saccopharynx harrisoni*, which is about 150 cm (59 in.) long. Marine biologists believe that the nets used to drag the depths can catch only the smaller, slower fish, while the others evade the nets. Modern deep-sea exploration vessels such as bathyspheres, equipped with powerful lights, television cameras, radar, and sonar, have made it possible to observe—fleetingly—a great variety of animals never seen before. Yet because of the difficulties presented by their habitat and the limited number of deep-sea exploration vessels available, very little is really known about abyssal animals. Only when man can bring these creatures to the surface, maintaining the temperatures and the pressures characteristic of their environment, will he be able to approach the challenges of abyssal biology. For the present, knowledge is limited to the few forms of abyssal life that have been observed in their environment and to those few animals that have been caught in the nets of the bathyspheres.

It is believed that a large number of abyssal species have a rather limited range in any particular sea. Yet closely related, if not identical, forms have been found in the most widely separated parts of the ocean.



8





PART 2

52	The Eye	64	The Muscles
56	The Nervous System	68	The Skeleton
60	The Skin		

MAN | the most versatile living creature

The human body is, indeed, a remarkable creation. Almost everyone is aware of the fantastic array of functions that it can accomplish; so familiar are these functions, in fact, that man's capabilities are often regarded as commonplace and somehow taken for granted. If the individual tissue and organ systems are examined in detail, however, the multitude of essential components for each function is clearly revealed, and the amazing capacities of the assembled whole human being fall into new perspective.

In this introductory volume of *The World of Science* selected examples of such systems are described: a sensory organ (the eye), the nervous system, two organs with multiple functions (the skin and bones), and an organ involved in movement (the muscles).

An example of the close cooperation among these systems is presented in "The Eye" (p. 52). Described here are the protective mechanisms furnished to the eye by the skin and bones, the function of the muscles in changing the shape of the lens, and the transformation into visual images by the brain of electrical stimuli sent through the optic nerve from the retina. However, the specialization of the various components of the eye itself is what most fascinates us: the ability of the iris to control the amount of light entering the eye, of the lens to focus the image on the retina, and of the retinal cells to convert light energy into electrical energy.

The many anatomical structures of the central and peripheral nerve tissues are well described in "The Nervous System" (p. 56). This article explains, for example, how it is possible for sensory impulses to be received by the brain from the foot and motor impulses to be sent by the brain to the foot in less than one second. Again, the efficient cooperation among systems is emphasized—in this instance, between the nervous system and such other systems of the body as the

muscles, the glands, and the organs of circulation and respiration.

An organ with a considerable variety of responsibilities is described in the article, "The Skin" (p. 60). Perhaps its best-known function is that of protecting the body from invasion by microbes and other foreign matter as well as from excess sunlight and dehydration. The skin also houses sensory nerve endings, and acts as a temperature-monitoring component of the body's thermoregulatory mechanism. Moreover, the skin is an important excretory organ; waste products are secreted by its sweat glands and, in the female, milk is secreted by its mammary glands.

Unlike the skin, muscles have essentially a single function: to contract, so that the parts to which they are attached, or in which they are housed, will move. "The Muscles" (p. 64) explains how these organs are arranged as opposing members of a pair so that a part—such as a bone or intestinal segment—is moved during contraction of one member; and while that member relaxes, the part can be returned to its original position by constriction of the other member of the pair. Again, examples of organ interaction appear: nerve control of contraction and relaxation, and nourishment provided by the circulatory system.

The skeleton has three obvious functions: protection (especially of the brain, heart, and lungs), structural support, and, with the muscles, movement. A less well-known, but vital, function is that of housing the blood-cell-forming tissues within the marrow of some bones. The kinds of bones and examples of their functions are described in "The Skeleton" (p. 68).

By these examples, the reader will understand that not only is the human body composed of a variety of intricately working parts, but that each of these depends on and helps control the others. When this intricacy of the body is understood,

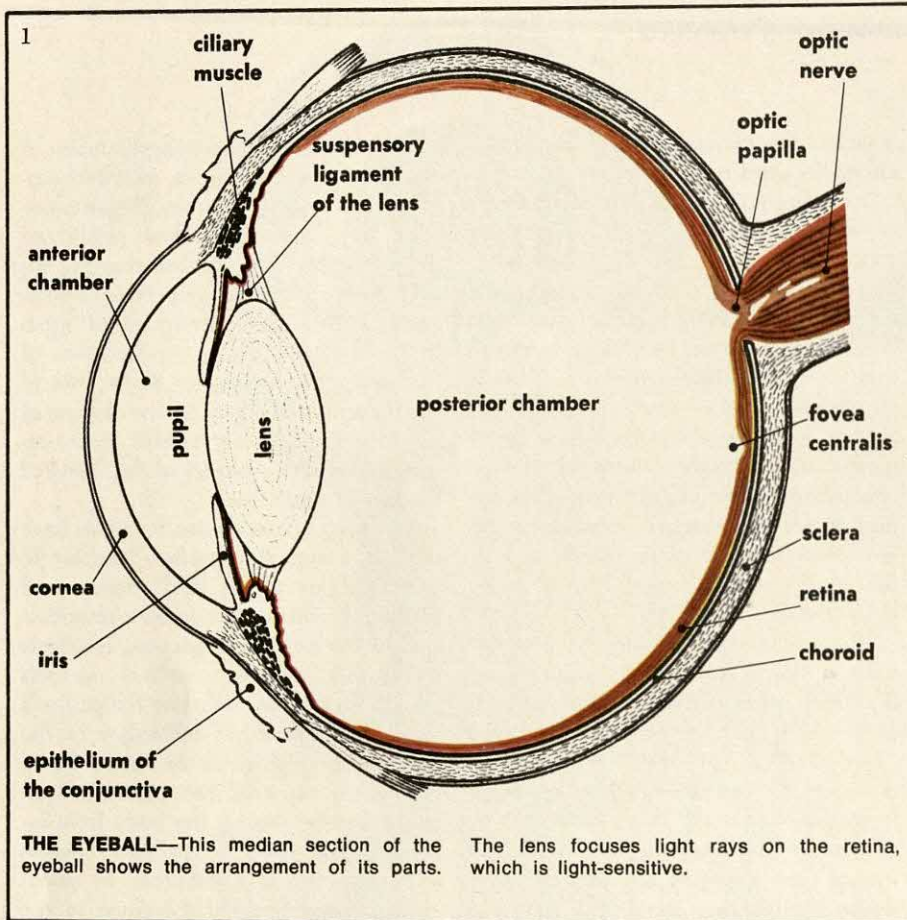
recent advances in the transplantation of organs—either human or artificial—appear all the more wondrous. Organ transplantation, one of the most publicized developments in the field of surgery, has been hampered by the rejection phenomenon. Rejection of a transplanted organ is characterized by an accumulation of the patient's lymphocytes at the site of the transplanted organ, by the clotting of blood in the capillary vessels of the organ, and by disturbances of the lining of the blood capillaries.

To counter those effects, scientists have devised a typing procedure, similar to that used for typing blood donors and recipients, which is based on a classification of the small lymphocytes. In efforts to prevent rejection, various methods have been tried for reducing the patient's capacity to produce antibodies in the small lymphocytes. All the agents tested tended to suppress the patient's antibodies, which protect the body from infection; and thus the patients become vulnerable to such ailments as pneumonia. Some form of tolerance to the transplant seems to develop after six months or longer, however, decreasing the need for immunosuppressive agents.

The first transplants—those of the cornea of the eye—date from the 1930s. They have been largely successful, because there are no blood vessels in the cornea. Kidney transplantation, begun in the early 1950s, was the next major advance; by 1970, a patient with a kidney transplant who survived the first three months had about an 80 percent chance of living three years or more. Heart transplantation continued to be a complex problem, although the relatively simple operative procedure has been performed widely since the first such operation in 1968.

In Volumes 2 and 3, some 75 additional articles will help the reader understand more fully the inner workings and interdependency of his body's parts—from the kidney to the nervous system.

THE EYE | light stimuli become images

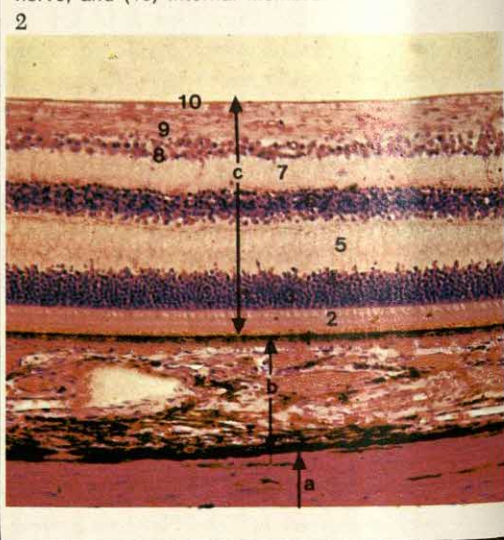


This pigment is completely lacking in albino individuals, whose irises are red because the blood circulating through the eye is visible through the unpigmented iris.

Almost at the center of the iris is an opening, the pupil. The iris acts as a diaphragm; in dim light it increases the size of the pupil, and in bright light it decreases it. When viewing nearby objects, the iris constricts, thus making the objects appear more clearly.

The second part of the middle layer is the ciliary body. It consists largely of

HISTOLOGICAL SECTION OF THE SCLERA, CHOROID, AND RETINA OF THE HUMAN EYE—The illustration shows the three layers that make up part of the human eye: **a** the sclera, **b** the choroid, and **c** the retina. The retina has several layers: (1) pigmented cells, (2) layer of cones and rods, (3) external membrane, (4) external nuclear layer, (5) layer of synapses between the rods and the bipolar cells, (6) bipolar cell layer, (7) layer of synapses connecting the bipolar cells with the ganglion cells, (8) layer of the ganglion cells, (9) layer of the fibers leading to the optic nerve, and (10) internal membrane.



The eye is perhaps the most important of the sense organs of the human body. It receives external light stimuli and transmits nervous impulses to the central nervous system, where they are transformed into visual sensations. The organ of sight is constituted essentially of the two eyeballs, each of which is located in an orbital cavity in the anterior portion of the skull and protrudes slightly from it.

The eyebrows and eyelids protect the eyes against irritating agents such as sweat and dust and against excessively bright light. Tears secreted by the lacrimal glands (tear glands) are spread over the cornea by the blinking of the eyelids. This continuous bathing of the cornea removes dust and bacteria that might otherwise produce injury or infection.

The eyeball is a nearly spherical organ surrounded by three layers: an outer

fibrous layer; a middle layer, rich in blood vessels; and an inner layer, containing the nerve endings. Each of these layers has its own clearly differentiated parts.

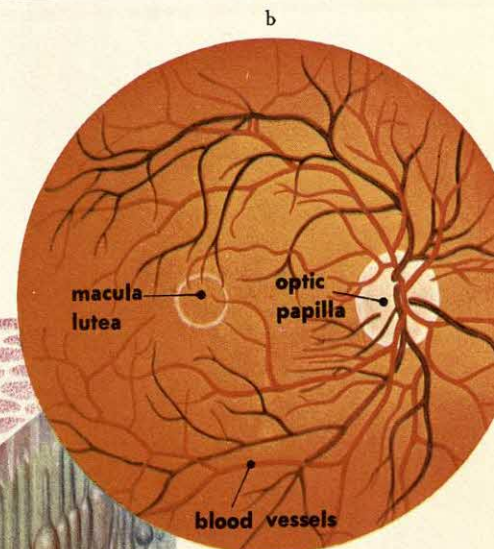
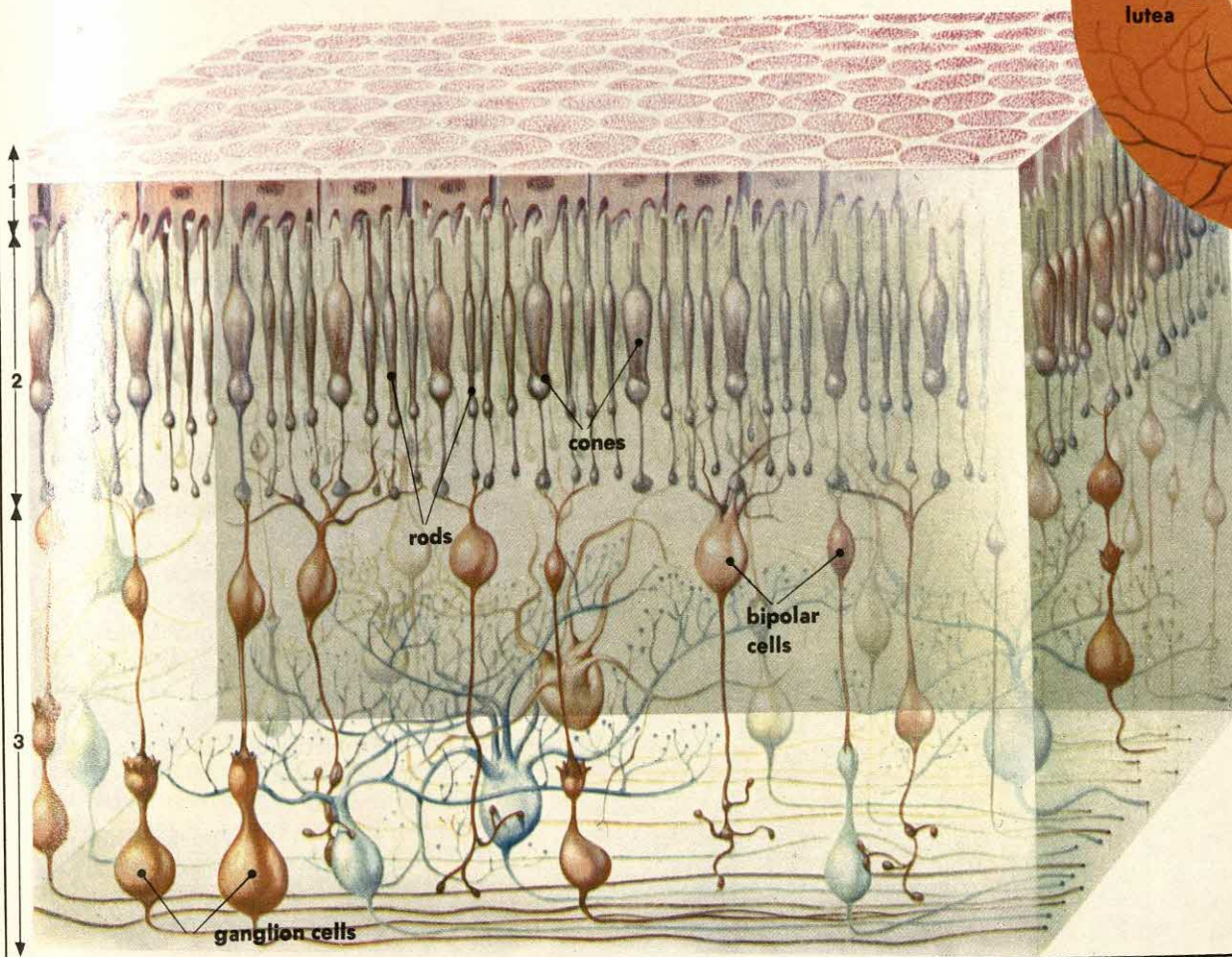
The anterior, transparent portion of the outer layer is the cornea. The remainder of this layer is the opaque sclera, the white of the eye, which completely surrounds the posterior part of the eye. The appearance of the sclera changes with the passage of time. In children it is a bluish-white, but with the advance of years, it tends to become yellowish-white.

The middle layer consists of three parts. The anterior part is the iris, which lies a short distance behind the cornea. Between these two parts is a small chamber, the anterior chamber, which contains the aqueous humor. The color of the iris differs from individual to individual and depends on its pigmentation, which is determined by genetic factors.

ciliary muscle, which is attached to a ligament that holds the crystalline lens immediately behind the iris and the pupil. The third part of the middle layer is the choroid, located behind the ciliary body and adhering to the internal surface of the sclera. Blood vessels in the choroid, which also contains pigmented cells,

STRUCTURE OF THE OPTIC RETINA—The retina (Illustration 3a) can be generally considered to be formed of three layers: The first is a layer (1) of pigmented epithelial cells that contain granules of dark pigment; this layer is adjacent to the choroid, to which the retina is attached. The surface of these cells next to the choroid is flat, but the opposite surface has parts that extend among the rods and cones. The second layer (2) consists of photoreceptor cells, and rods and cones; these are

the sensory elements of the retina that transform light energy into nervous impulses. The third layer (3) consists of bipolar cells and ganglion cells over which nervous impulses from the rods and cones travel to the optic nerve and the brain. Illustration 3b shows the posterior portion of a normal eye, with the optic papilla, the point at which the optic nerve emerges from the retina, and the macula lutea, in which the sensitivity of the retina is greatest.



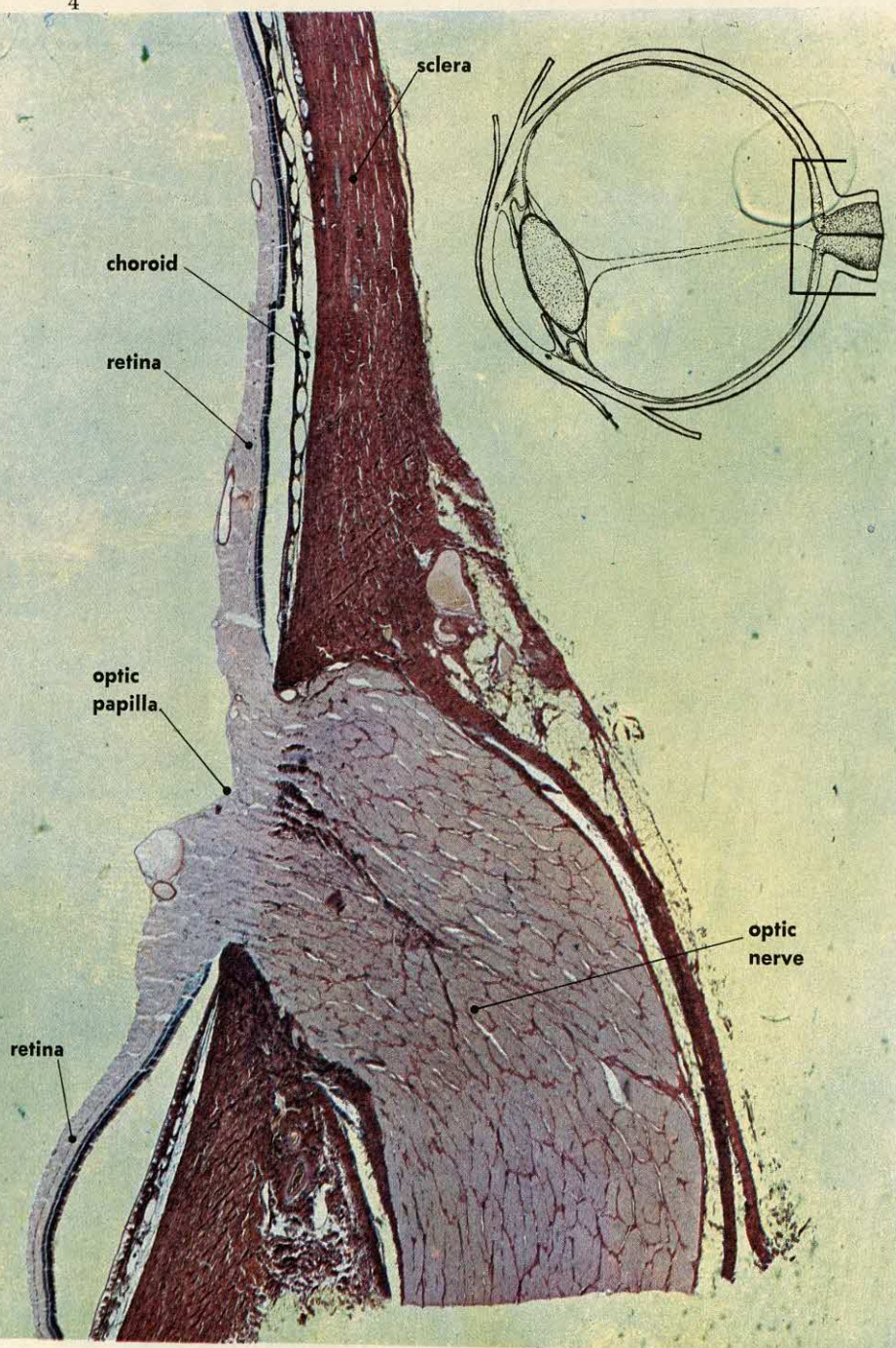
nourish the eye tissues.

The inner layer is the retina, lying immediately to the inside of the choroid. Only the optic retina, the posterior portion of the retina, is involved in vision. The anterior portion, which extends to the ciliary body, is the blind retina. The dentate border between the optic retina

and the blind retina is the ora serrata.

The retina looks like a thin, transparent sheet, but microscopic examination reveals that it is composed of several layers. The outermost layer consists of pigmented cells. The next layer contains the light-sensitive cells that are called rods and cones because of their shapes.

The cones function best in bright light, the rods in dim light. Both contain rhodopsin, a pigment known also as visual purple. The thin, external membrane separates this layer from the next one, the outer nuclear layer, which consists of extensions of the rods and cones and contains their nuclei. Next is a layer of bi-



THE BACK OF THE EYE—The retina, which consists of nerve tissue, is the sensory part of the eye. It is the innermost layer surrounding the posterior chamber of the eye. At the

back of the retina is the optic papilla, the point where the optic nerve enters the retina. Exterior to the retina are the choroid and the sclera.

polar cells, and to the inside of this is a layer of ganglion cells. Fibers of the ganglion cells run horizontally along the retina to the optic nerve, which extends from the posterior part of the retina to the brain. The innermost part of the retina is lined by the internal membrane. The rods, cones, bipolar cells, and ganglion cells are all nerve cells. They do not actually touch each other but are separated by synapses, small spaces across which nervous impulses travel from cell to cell.

The sclera, choroid, and retina surround the posterior chamber, a large cavity containing the vitreous humor, a thick, transparent liquid. The anterior chamber and the posterior chamber are separated by the crystalline lens.

The crystalline lens is transparent and biconvex (convex on both sides). The ciliary muscles and suspensory ligaments that support the lens also change its shape. When the eye focuses on distant objects, the lens is flat; when the eye focuses on nearby objects, the lens is rounder.

When light enters the eye, it passes through several retinal layers until it reaches the rods and cones. Here the light energy is absorbed by the rhodopsin and is transformed into electrical energy that passes along the nerve cells as a nervous impulse. The impulse travels from the rods and cones across synapses to the bipolar cells, then across other synapses to the ganglion cells, the fibers of which form the optic nerve and lead to the brain. Here the nervous stimuli are transformed into a visual image.

The place at which the optic nerve departs from the retina is the optic papilla, or blind spot. There are no light-sensitive cells here, and light focused at this spot cannot be seen.

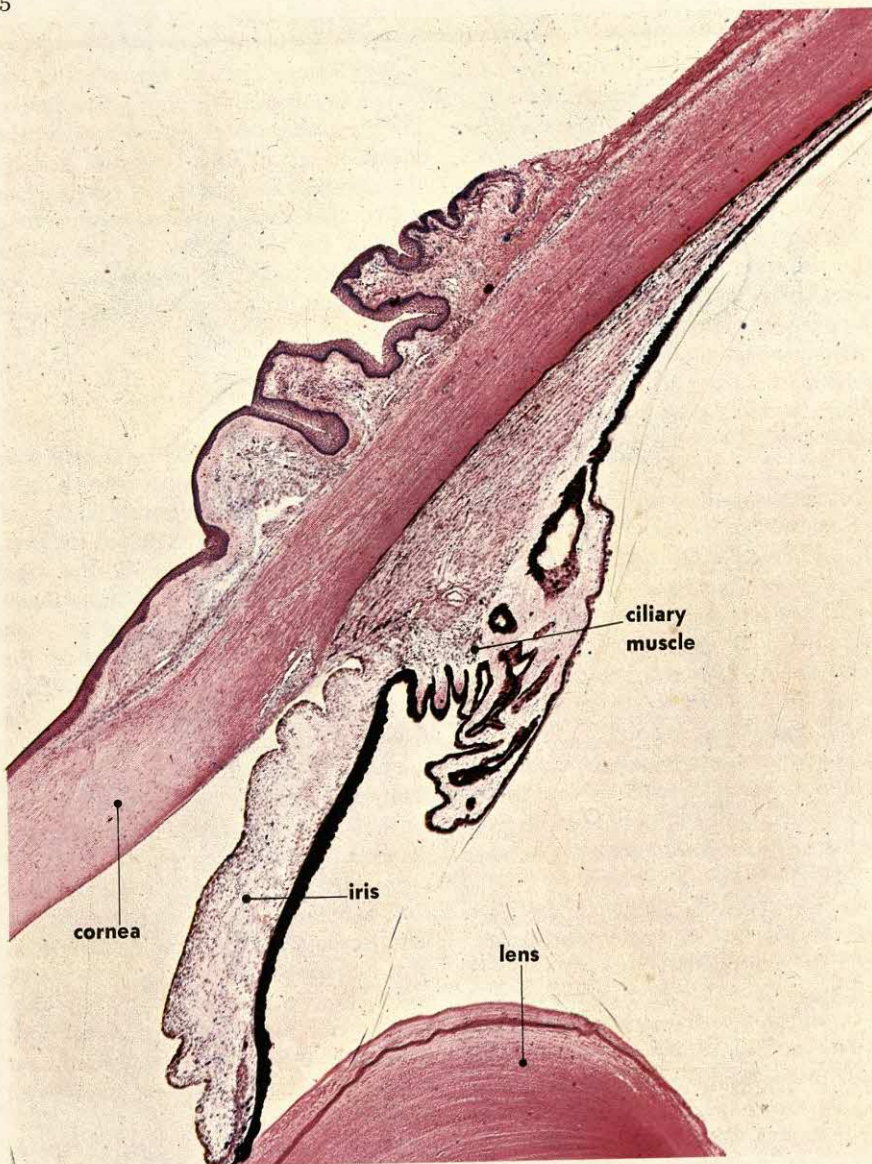
A circular area of the retina that is directly behind the pupil and the lens is the macula lutea. At its center is a depression, the fovea centralis; here the visual sensitivity of the retina is greatest. This area is well supplied with cones and has only a few rods.

5 The eye is sometimes compared with a camera; both retina and film are light-sensitive. The iris of the eye and the diaphragm of the camera both control the amount of light that reaches the light-sensitive elements. The lens of the eye and the lens of a camera both focus light rays on the light-sensitive element, but in different ways: the lens of the eye changes shape, while the lens of the camera changes its position relative to the film.

COMMON OPTICAL DEFECTS

Accommodation, the adjustment for different distances, is achieved in the human eye by changing the curvature of the crystalline lens and thus modifying the refractive power of the eye. An unaccommodated eye in which the image of a distant object falls on the retina is a normal, or emmetropic, eye. This eye sees distant objects clearly. Ametropia—any deviation—results from an abnormality in the relation between the axial length of the eye and its refractive power. The two main types of ametropia are well known: hypermetropia, or hyperopia, and myopia. In hypermetropia, the image of a distant object falls behind the retina. A person who has this condition is described as farsighted; he must accommodate even for distant vision. In myopia, the image falls in front of the retina, and the subject is described as nearsighted; he can see only near objects clearly. Another variant in the refractive state is astigmatism, a deviation from the spherical, which is very common in human eyes. This defect results from asymmetry in the curvature of the refractive elements (lens and cornea). Hereditary factors play a prominent part in these variations, which are correctable with eyeglasses or contact lenses.

The power of accommodation diminishes with age, and the resulting condition is known as presbyopia. The muscle of accommodation, situated in the ciliary body, enables the lens to adjust its focus by changing its thickness and the curva-



THE IRIS—The iris is located in front of the ciliary body and the crystalline lens. It is a colored, disk-shaped structure at right angles to the optic axis of the eye. Its outer edge is inserted in the angle formed by the sclera and the cornea. Its center is the aperture known

as the pupil; immediately posterior to it is the crystalline lens. The diameter of the aperture of the pupil varies with the intensity of light striking the eye. The suspensory ligament is barely visible in this photograph; it extends between the ciliary muscle and the lens. (6 X)

ture of its surfaces. A normal, gradual increase in the size of the nucleus, or hard center, of the lens causes a loss in elasticity and the corresponding impair-

ment of near vision that is characteristic of middle age in man. The change usually is greatest between the ages of 40 and 50.

THE NERVOUS SYSTEM |

the components of the central nervous system

All but the simplest animals require a means of coordinating the activities of the several types of cells and tissues that make up their bodies. Each process must occur only at its appropriate time and at appropriate rates. When the need arises, some processes—the contraction of muscle cells, for example—must happen immediately and must stop just as quickly. The function of coordinating all the parts of the body is assumed in part by the nervous system. Its individual cells, called neurons, transmit nervous impulses quickly from one part of the body to another. Impulses may travel from foot to brain and back to the foot in less than a second.

Each neuron has two long, threadlike extensions that branch near their tips. One extension is the *dendrite*; the other is the *axon*. Impulses received by the dendrite are transmitted to the cell body and then to the axon. From the axon the impulses are transmitted to the dendrite of another neuron or to a muscle or gland, stimulating it to act.

The nervous system of the human body is divided into two parts: the central nervous system and the peripheral nervous system. The central nervous system is composed of the brain and the spinal cord. The peripheral nervous system consists of 43 pairs of nerves that extend from the central nervous system to the various parts of the body. Twelve pairs of cranial nerves serve primarily the head and the neck, and 31 pairs of spinal nerves serve primarily the trunk and the limbs.

All stimuli impinging on the body initiate impulses that travel to either the spinal cord or the brain or both. Each nerve of the peripheral nervous system contains both sensory and motor neurons. The sensory neurons have their receptive dendrites in the skin, in the sense organs, and in some internal organs. When these receive stimuli, either from the exterior environment or from internal organs, the sensory neurons transmit the stimuli to the central nervous system. Within the

brain or spinal cord, the impulses are relayed to connector neurons and then to motor neurons, which transmit the impulses to muscles or glands. The muscles are then stimulated to contract or the glands to secrete their hormones. It is by the appropriate relaying of nervous impulses that the central nervous system controls the coordination of the various parts of the body and brings about proper adjustments to changes in the environment.

THE SPINAL CORD

The spinal cord is a cylindrical cord consisting of nervous tissue. It extends from the brain through the neural arches of the vertebrae in the vertebral column, which protects it from injury. For most of its length the spinal cord has a diameter of about 1 cm (about 0.4 in.), but it has a cervical enlargement where the nerves that supply the arms originate (from the third cervical vertebra to the second thoracic vertebra), as well as a lumbar enlargement where the nerves that supply the legs originate (from the ninth thoracic vertebra to the first lumbar vertebra). Immediately below this is the *conus medularis*, a portion of the spinal cord that tapers into a fine filament, the *filum terminale*. The *filum terminale*, in turn, extends to the coccyx near the lower end of the vertebral column. The dorsal and ventral surfaces of the spinal cord each have three longitudinal fissures or sulci—a median fissure and two lateral fissures.

A cross section of the spinal cord shows a butterfly-shaped area of gray matter surrounded by white matter. The gray matter contains the nerve cell bodies, and the white matter contains their axons and dendrites. In the center of the gray matter is the central canal.

The spinal cord and the brain are covered by three meninges or membranes—*pia mater*, *arachnoid*, and *dura mater*. The innermost membrane is the *pia*

mater, which contains blood vessels that serve the spinal cord and the brain. The outermost is the *dura mater*, which is tough and has a protective function. Between them is the *arachnoid* with a pattern resembling that of a spider web. Cerebrospinal fluid occupies the space between the *arachnoid* and the *pia mater*. The fluid acts as a protective cushion around the spinal cord and brain.

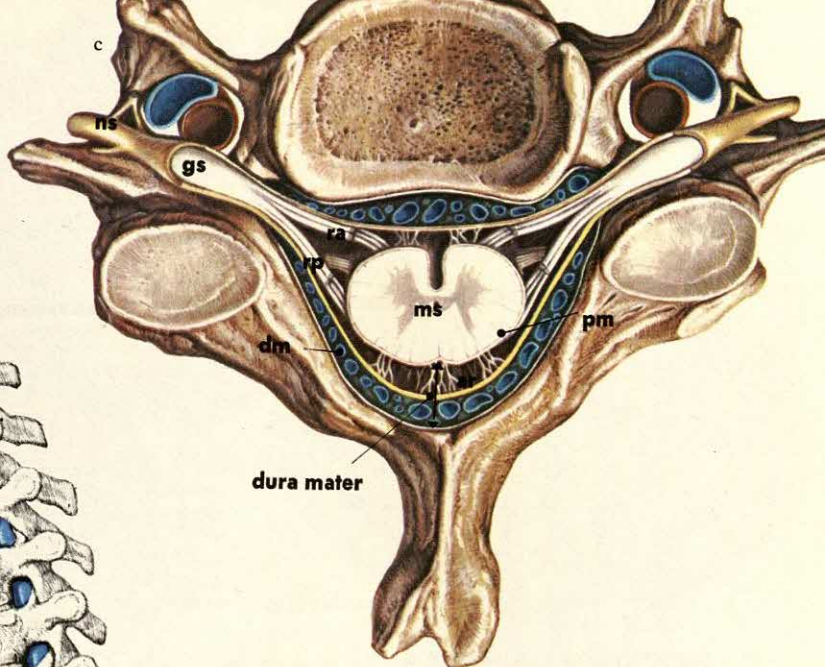
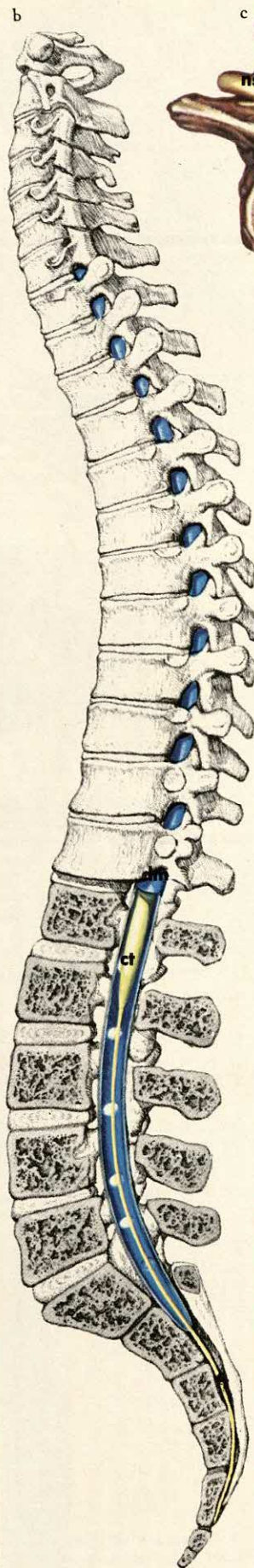
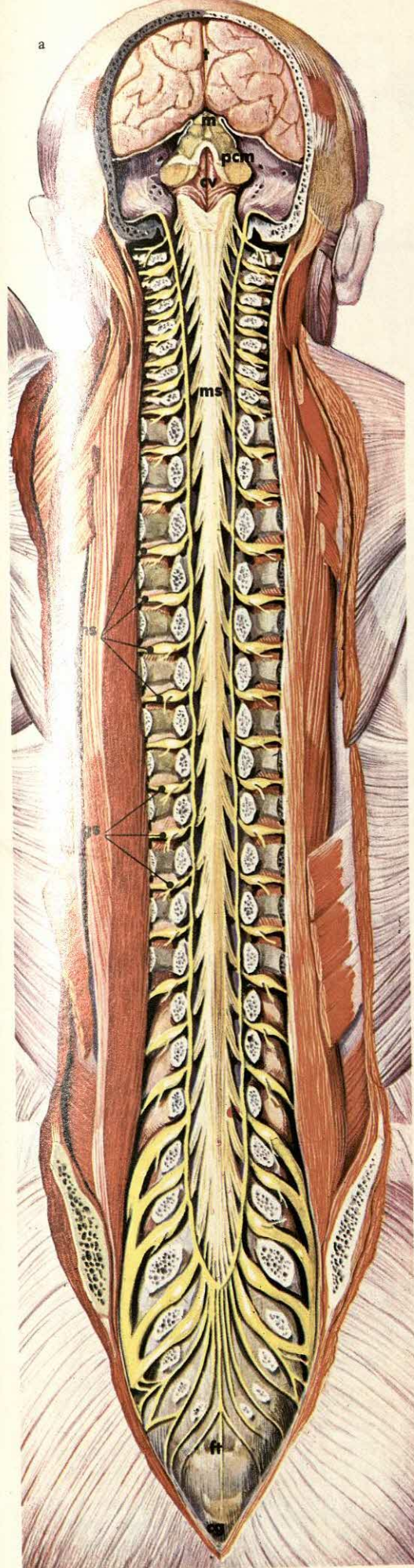
THE BRAIN

The brain, or *encephalon*, is the most complex part of the central nervous system; through it pass nervous impulses that control most of the activities of the body. Roughly hemispherical in shape, the brain and much of its surface are convoluted by fissures. The brain has three major areas: the hindbrain, the midbrain, and the forebrain. The hindbrain and the midbrain comprise the brain stem, which is continuous with the spinal cord.

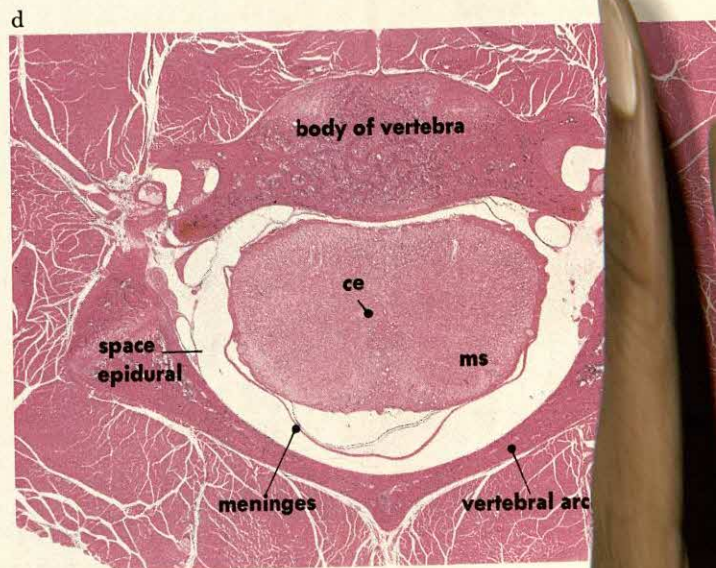
THE HINDBRAIN

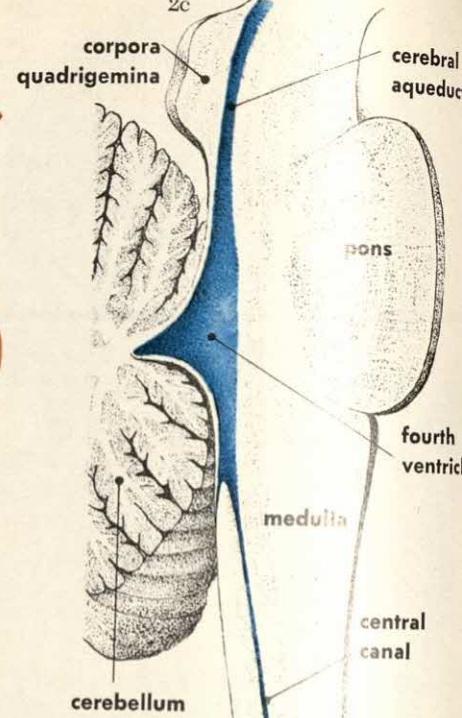
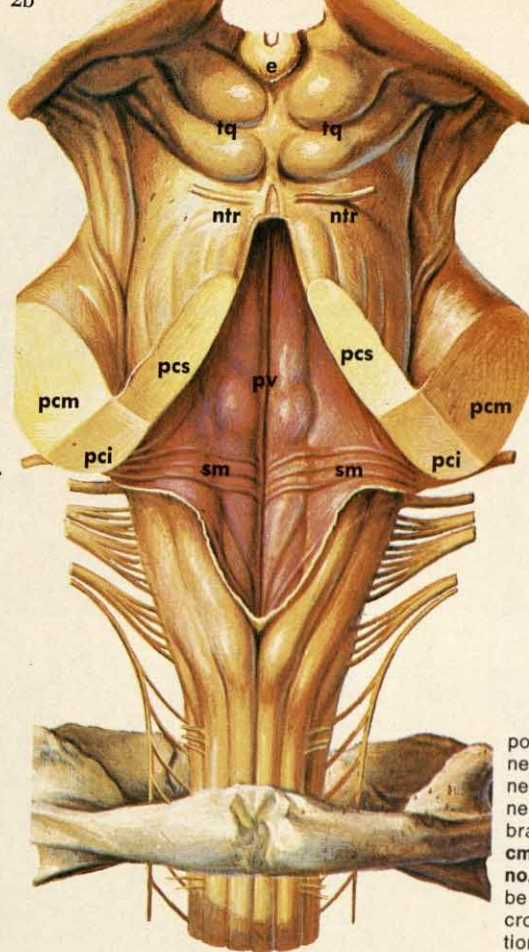
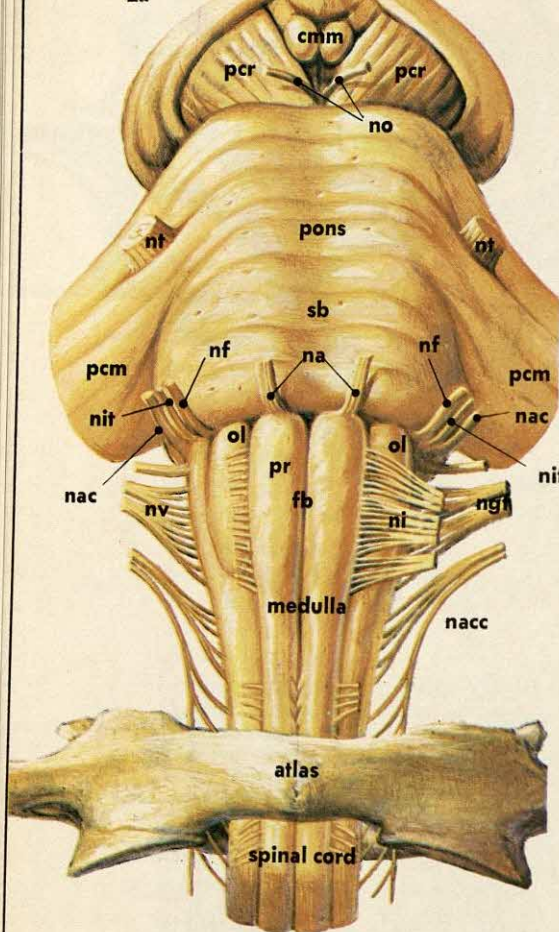
The hindbrain consists of three parts: the medulla (or medulla oblongata), the cerebellum, and the pons. The medulla, which is a continuation of the spinal cord, controls some involuntary functions, such as heartbeat, circulation, respiration, and swallowing. It also carries neurons from the spinal cord to the upper areas of the brain. The central canal of the spinal cord continues upward through the medulla where it enlarges into a bigger opening, the fourth ventricle of the brain. Blood vessels in the linings of this and the other ventricles secrete the cerebrospinal fluid.

The cerebellum is connected to the rest of the brain by three pairs of cerebellar peduncles. One pair (the inferior cerebellar peduncles) is connected with the medulla, one (the median cerebellar peduncles) with the pons, and one (the superior cerebellar peduncles) with the



THE CENTRAL NERVOUS SYSTEM—Illustration 1a shows the central nervous system with the cranium and the vertebral canal opened and the cerebellum removed. From top to bottom: the telencephalon *t*; midbrain *m*; under the midbrain, the median cerebellar peduncle *pcm* in section; the fourth ventricle *cv*; and the spinal cord *ms*, at the sides of which the spinal nerves *ns* and spinal ganglia *gs* are visible. The spinal cord tapers markedly toward its extremity, the filum terminale *ft*, which is joined to the coccyx *cg*. The filum terminale is also visible in Illustration 1b, in which the lumbar and sacral portions of the vertebral columns are shown in section to reveal the conus medullaris *ct* and the extent of the dura mater *dm*, the outermost of the membranes lining the central nervous system. Illustration 1c is a cross section of the spinal cord *ms* at the level of a cervical vertebra. It shows the three membranes, or meninges, that enclose the central nervous system. From the outermost, they are the dura mater *dm*, the arachnoid *ar*, and the pia mater *pm*. The ventral root *ra* and the dorsal root *rp* emerge from the spinal cord and form the spinal nerve *ns* beyond the spinal ganglion *gs*. Illustration 1d is a photomicrograph of a cross section of a vertebra. Muscles *mm* surround the vertebra. At the center of the cord is the central canal *ce*. The meninges were slightly altered in the preparation of the slide. (7 X)



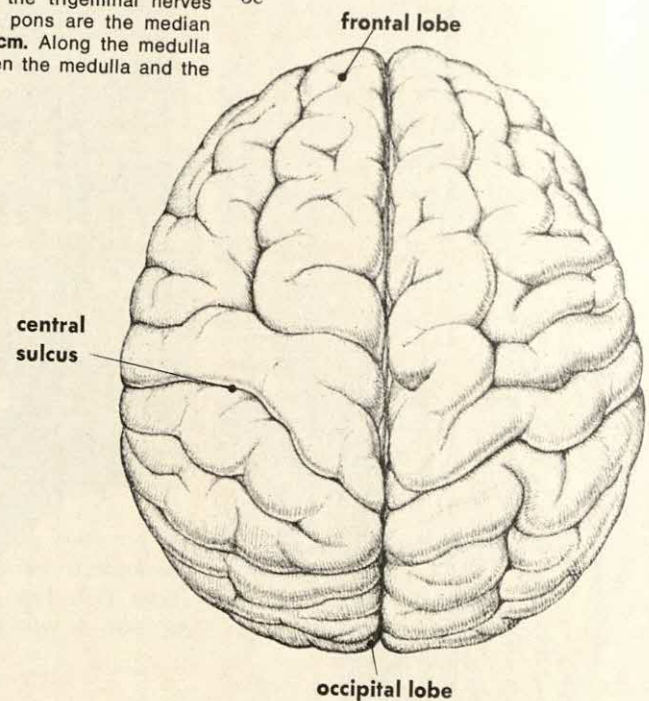
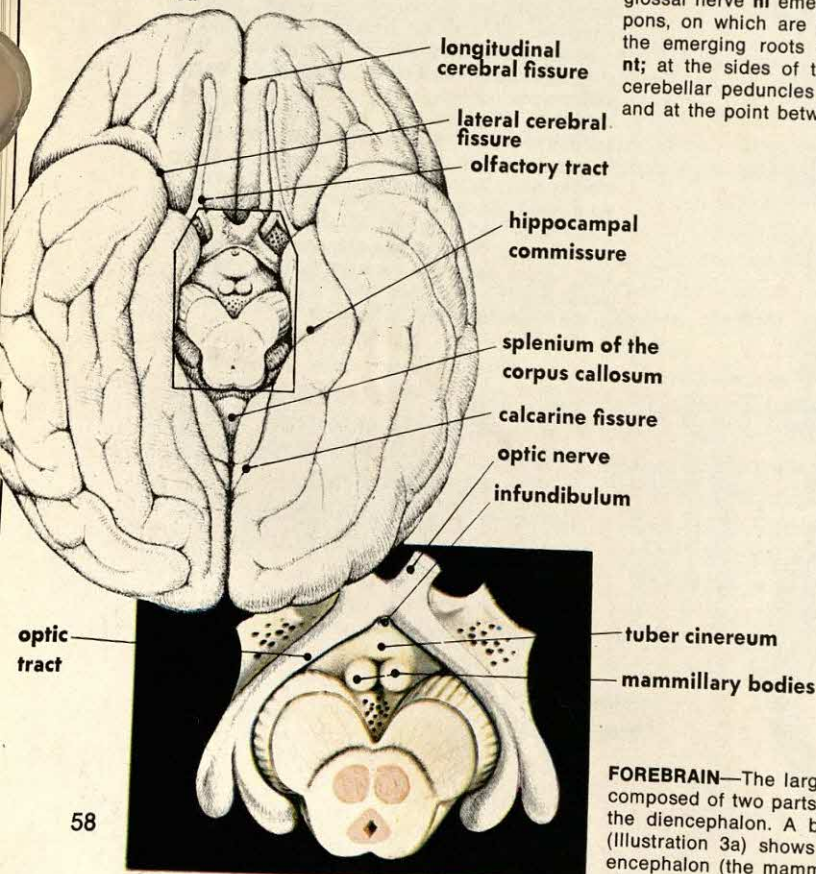


pons are the emerging roots of several cranial nerves: the vagus nerve **nv**, the intermediate nerve **nit**, facial nerve **nf**, and the abducent nerve **nacc**. The midbrain contains the cerebral peduncles **pcr**, the mammillary bodies **cmm**, and the roots of the oculomotor nerve **no**. On the dorsal surface (Illustration 2b) can be seen the floor of the fourth ventricle **pv**, crossed by the medullary striae **sm**, and sectional views of the cerebellar peduncles: inferior **pci**, median **pcm**, and superior **pcs**. The roots of the trochlear nerve **ntr** appear above, with the corpora quadrigemina **tq** and the epiphysis **e**. In Illustration 2c the intercommunicating cavities between the structures previously described are shown in blue.

3c

MEDULLA, PONS, AND MIDBRAIN—The ventral aspect of these parts is shown in Illustration 2a and the dorsal aspect in Illustration 2b. On the ventral surface the pyramids **pr** are visible,

separated by the ventral median sulcus **fb**; the olivary bodies **ol** are located at the sides of the pyramids and are separated from them by a fissure from which the roots of the hypoglossal nerve **ni** emerge. Above these lies the pons, on which are the basal sulcus **sb** and the emerging roots of the trigeminal nerves **nt**; at the sides of the pons are the median cerebellar peduncles **pcm**. Along the medulla and at the point between the medulla and the



FOREBRAIN—The largest part of the brain is composed of two parts, the telencephalon and the diencephalon. A basal view of the brain (Illustration 3a) shows some parts of the diencephalon (the mammillary bodies, the tuber cinereum, the infundibulum, the optic chiasma)

and part of the corpus callosum, which joins the two hemispheres of the telencephalon. Some of these parts are enlarged in Illustration 3b. Illustration 3c shows a dorsal view of the brain with its convolutions and sulci (fissures).

midbrain. The cerebellum consists of two hemispheres connected by a narrow body known as the vermis.

The main function of the cerebellum is the coordination of muscular movements. The exterior part of the cerebellum is a layer of gray matter with cell bodies, while the interior part consists of white matter with dendrites and axons. The two layers are intricately folded; if the cerebellum is cut open, it will reveal a branched pattern because of the foldings.

And finally, the pons transmits impulses between the two cerebellar hemispheres.

THE MIDBRAIN

The midbrain (mesencephalon) lies between the hindbrain and the forebrain, and relays messages between these two parts. On its surface are four small bodies, known as the corpora quadrigemina, which are visual and auditory reflex centers. The fourth ventricle of the medulla narrows into the cerebral aqueduct (aqueduct of Sylvius) in the midbrain.

THE FOREBRAIN

The forebrain (prosencephalon) consists of two parts: diencephalon and telencephalon. The diencephalon contains several important structures, among them the thalamus and the hypothalamus. The thalamus relays sensory impulses to the cerebral cortex of the telencephalon; the hypothalamus regulates body temperature, blood pressure, water, balance, appetite, sleep, and emotional behavior. The parts of the hypothalamus include the mammillary bodies, tuber cinereum, infundibulum, pituitary, and optic chiasma. The optic nerves extend from the optic chiasma to the eyes; the thalamus and hypothalamus surround the third ventricle, which is continuous with the cerebral aqueduct.

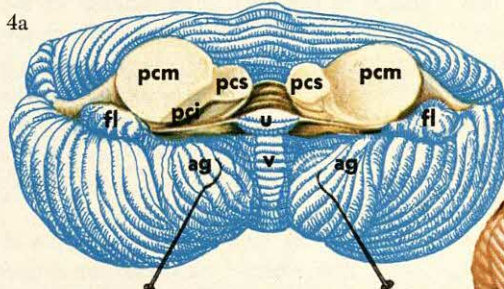
The telencephalon consists primarily of the cerebrum. The two cerebral hemispheres have a cortex of gray matter and an underlying layer of white matter. Each cerebral hemisphere contains a lateral ventricle that is continuous with the third ventricle of the thalamus. It is in the cerebrum that the senses are perceived; it is the center of conscious sensations, voluntary movements, memory, intelligence, and insight.

The rhinencephalon, a part of the telencephalon, is involved with the sense of smell. It contains the olfactory bulbs, which are connected to the cerebral hemispheres by the olfactory tracts. The olfactory nerves extend from the olfactory bulbs to the nose.

THE CEREBELLUM—The cerebellum is part of the hindbrain. Its two lateral parts, or cerebellar hemispheres, are joined by a central body called the vermis. Illustration 4a shows the cerebellum and the vermis *v* surrounding the superior, median, and inferior cerebellar

peduncles *pcs*, *pcm*, *pci*, the uvula *u*, the flocculi *fl*, and the amygdala *ag*, which appear to be folded. Illustration 4b shows the lower surface of the cerebellum with part of the pons *p*, the medulla *b* and the vermis *vr*.

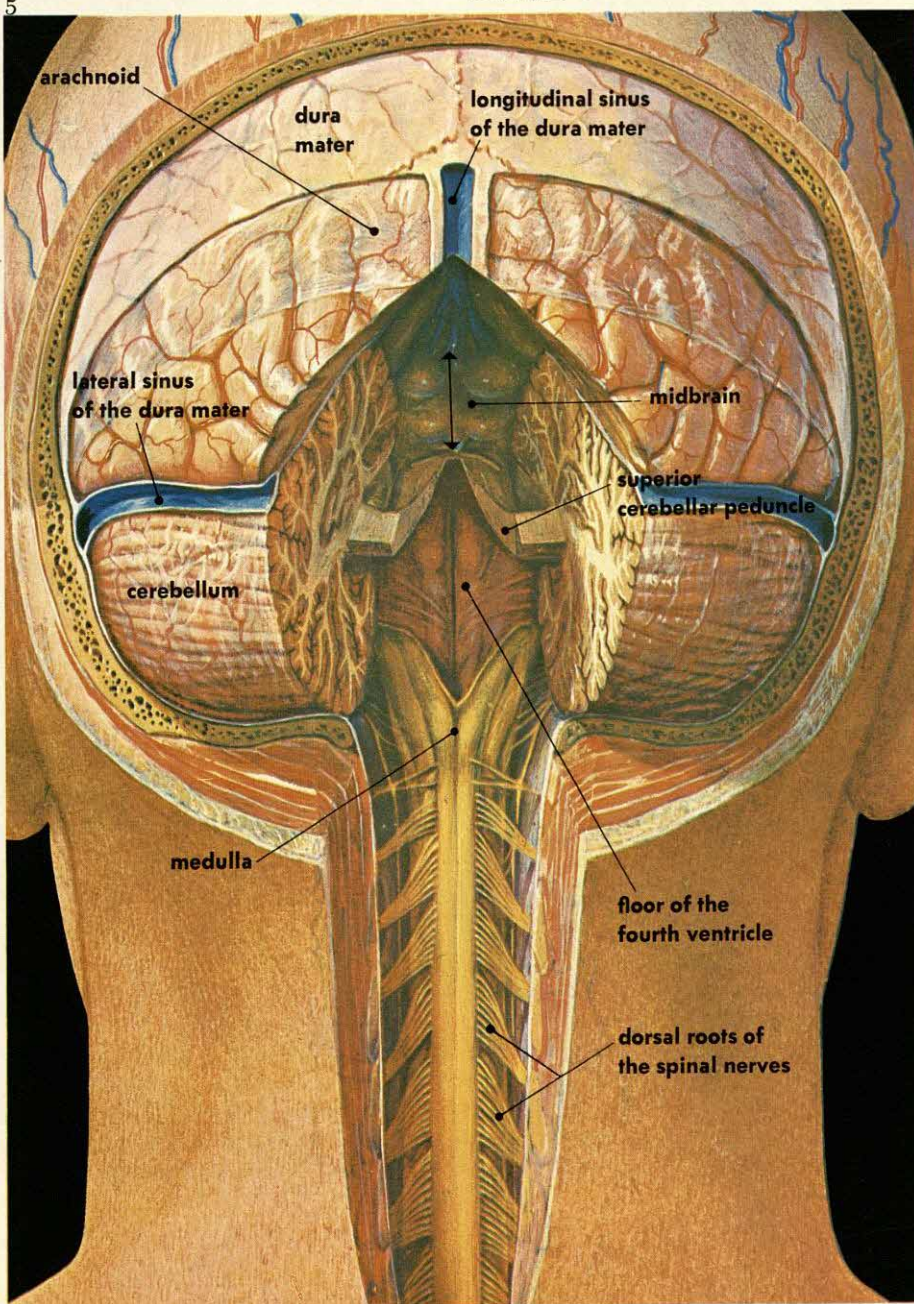
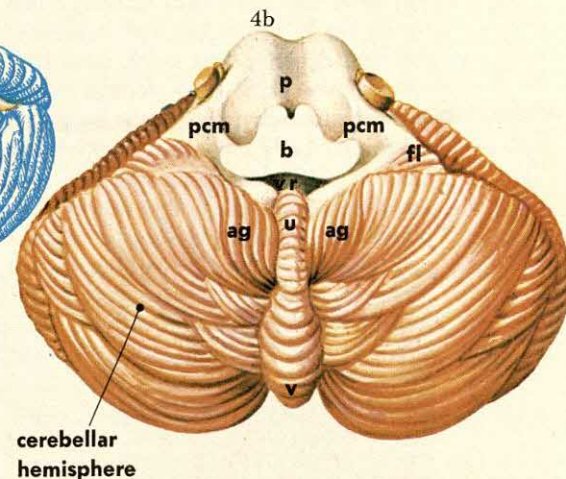
4a



DORSAL VIEW OF THE CRANIAL PORTION OF THE CEREBROSPINAL AXIS—In this view (Illustration 5) the cranium and the vertebral canal have been opened and part of the cerebellum and the occipital lobe of the brain have been cut away to show the dorsal surface of the brain stem and the anatomical relationships in this portion.

5

4b



THE SKIN |

nature's miraculous garment

The skin, that marvelous envelope that covers nearly all the external surfaces of the human body, does much more than merely cover it. It keeps foreign matter and bacteria from entering the body, and it prevents body fluids from evaporating too fast. The skin also contains a vast array of nerve endings that detect pain, pleasure, pressure, and changes in temperature; and it carries sweat glands that excrete waste products in watery solution. Normal body temperature is maintained in part by the nerves and sweat

glands of the skin. Pigmentation of the skin is believed to protect the body against the harmful effects of too much exposure to sunshine. The hair and nails of human beings are outgrowths of skin that have a protective function, just as scales, feathers, and claws have similar origins and functions in some animals.

The skin is made up of two layers of tissue, the dermis and the outermost layer, the epidermis. The thickness of the epidermis varies from 0.03 to 1.5 mm (about .001 to .06 in.), and that of the

dermis varies from 0.2 to 3 mm (about .008 to .12 in.). Beneath the dermis is the hypodermis, or subcutaneous connective tissue, which is not considered a part of the skin.

THE EPIDERMIS

The epidermis is composed of five layers. The deepest layer is the basal layer, or stratum basale, which is a single layer of cylindrical cells. Above it is the stratum spinosum, made up of irregularly shaped

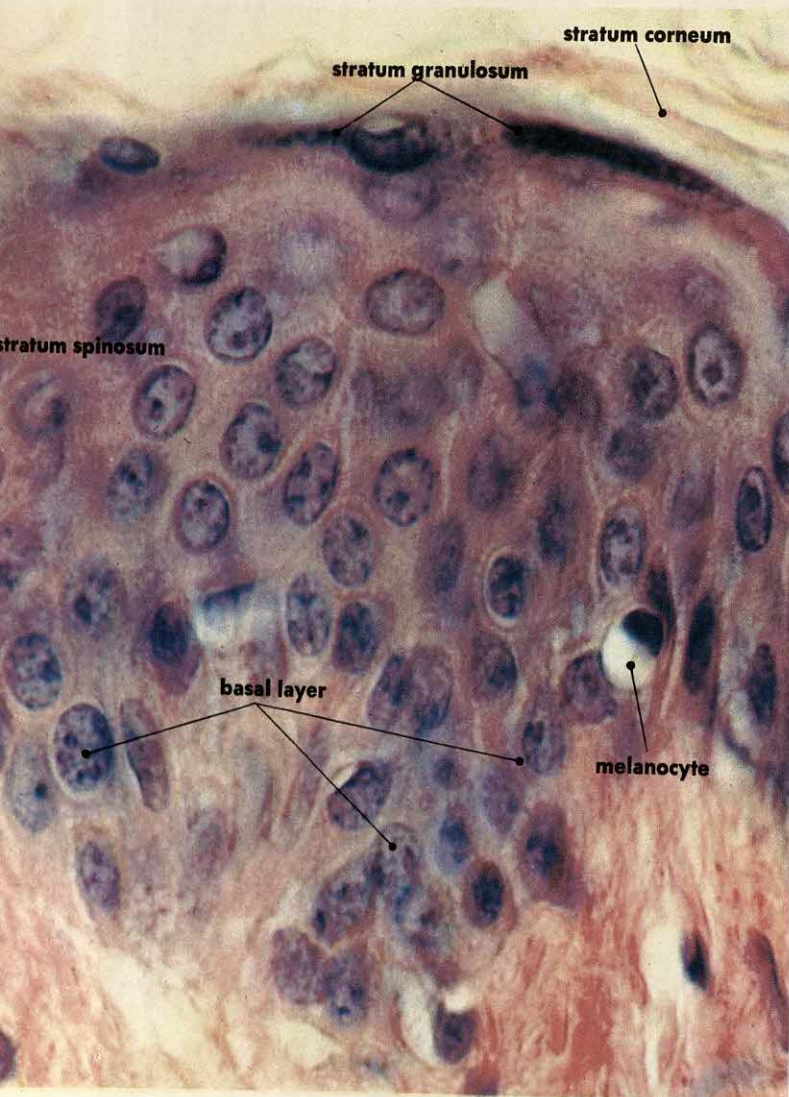
EPIDERMIS UNDER THE MICROSCOPE— Several layers of the epidermis are visible: the stratum corneum (the outermost layer, made up of dead cells); the stratum spinosum;

and the basal layer, made up of lighter cells, among which are melanocytes, which manufacture melanin. (1,500 X)

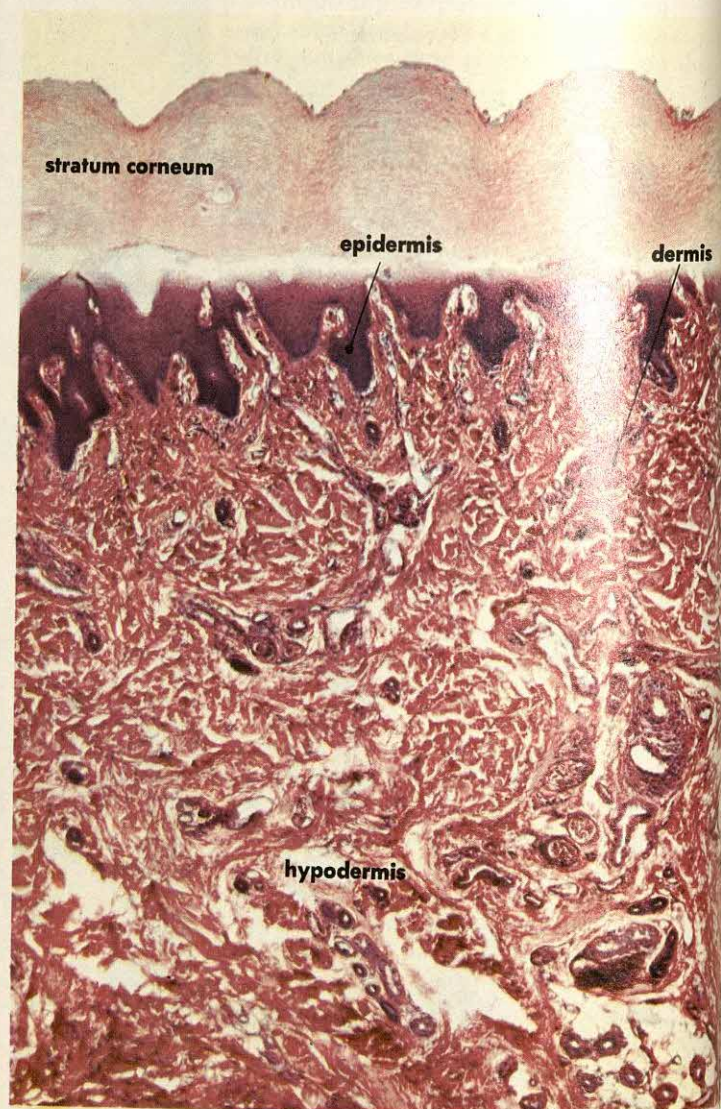
NAIL—The nail is composed of a thick, com-

pact stratum corneum that is rich in hard keratin. Underneath the nail is the dark epidermal layer, the dermis, and the hypodermis. (50 X)

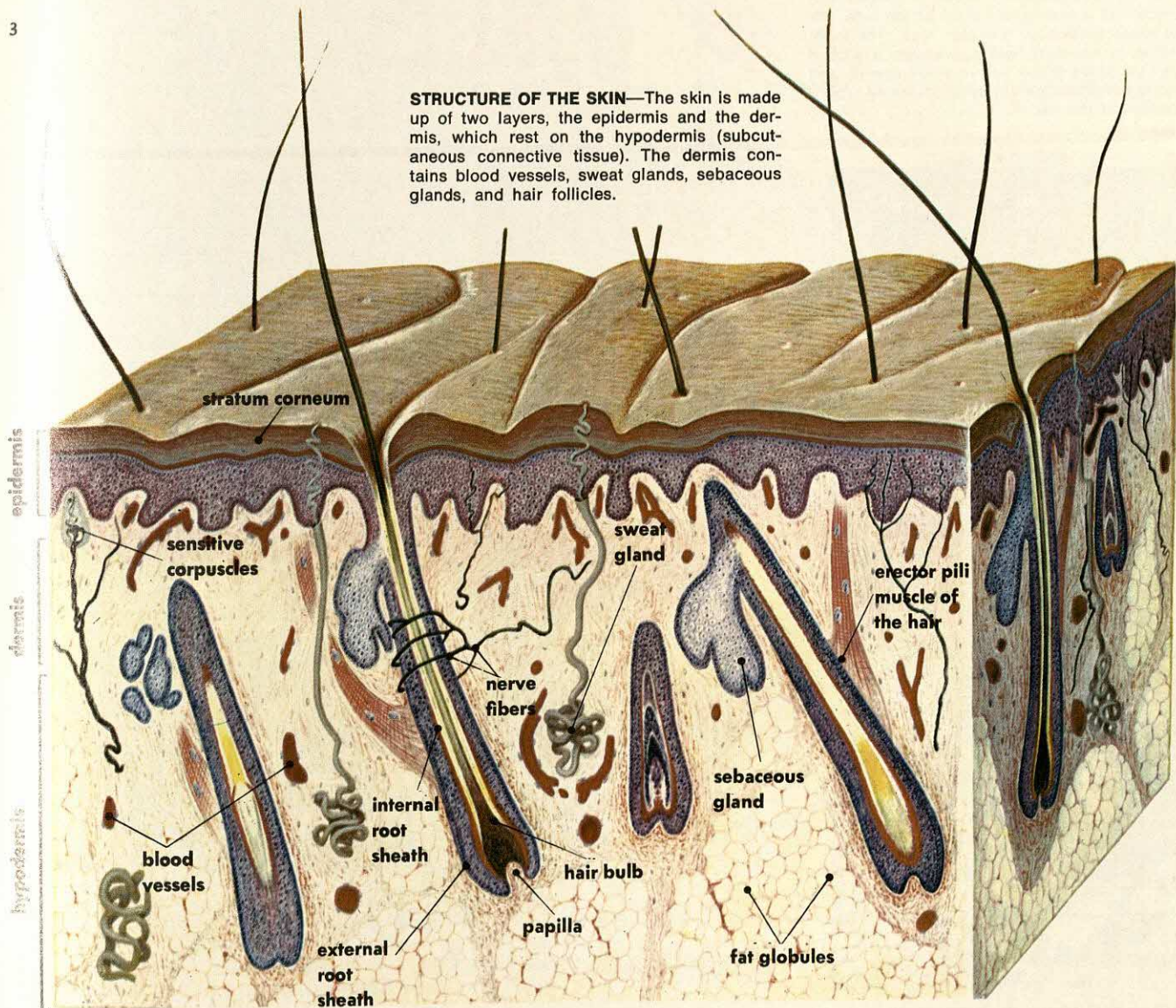
1



2



STRUCTURE OF THE SKIN—The skin is made up of two layers, the epidermis and the dermis, which rest on the hypodermis (subcutaneous connective tissue). The dermis contains blood vessels, sweat glands, sebaceous glands, and hair follicles.



cells called prickle cells; these cells are named for their short cytoplasmic spines, which apparently connect the cells like the pieces of a jigsaw puzzle. New skin cells are formed by cell divisions in these two layers.

Above the basal layer is the stratum granulosum, a layer made up of flattened cells containing a granular material, known as keratohyalin. This layer has the thickness of from two to four cells, or it may consist only of isolated cells.

The fourth layer is the stratum lucidum. It is composed of three to five layers of flattened, closely packed cells containing the substance eleidin, which

gives the cells a shiny appearance. Keratohyalin and eleidin are involved in the synthesis of keratin, a protein characteristic of skin, hair, and nails.

The uppermost layer is the stratum corneum, constituted of a varying number of layers of the remains of dead cells that contain soft keratin. The cells nearest the surface are microscopic scales that eventually flake off from the underlying cells and fall. They are replaced by cells formed in the Malpighian layer (the basal layer and stratum spinosum), which gradually move outward through the intervening layers and then die in turn, completing the cycle.

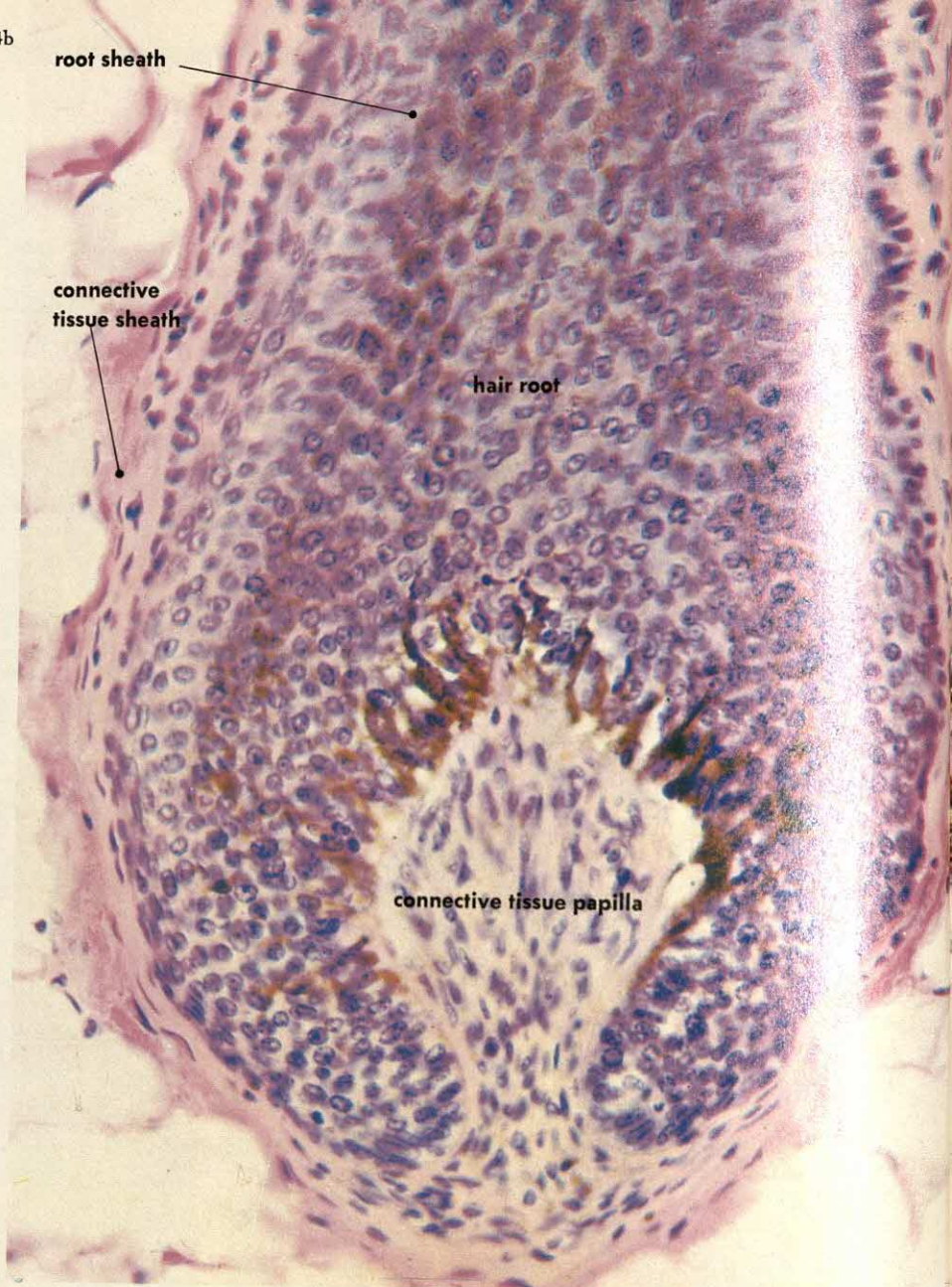
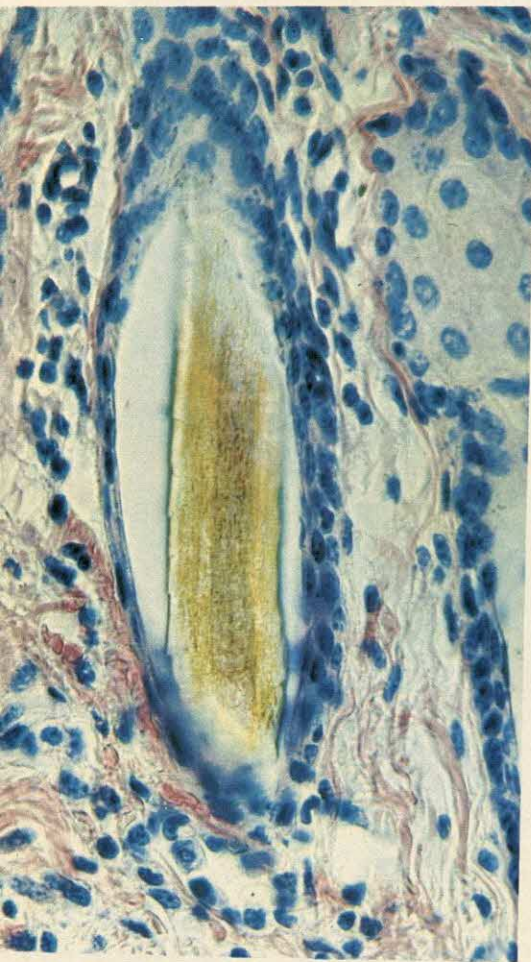
THE DERMIS

The dermis is made up of intertwined connective tissue that is indistinctly separated from the hypodermis. The dermis contains many elastic fibers, several groups of smooth muscle cells, and capillary blood vessels that nourish both the dermis and the epidermis.

In the dermis are nerve endings that collect various stimuli—physical, chemical, and mechanical. The dermis also contributes to the regulation of body temperatures by means of thermoreceptor corpuscles, sensitive to heat and cold, which transmit stimuli to the brain cen-

HAIR FOLLICLE—The follicles in which the hair originates are invaginations of epithelial tissue buried in the dermis. Illustration 4a shows a section of the hair follicle of a cat. (400 X) Illustration 4b shows a longitudinal section of a scalp hair follicle at the bulb, the terminal portion of the hair root. The bulb, which is markedly hollow, encloses a portion of connective tissue rich in blood vessels and nerves that nourish the cells governing regeneration of the hair.

4a



ters that control the regulation of the body temperature.

PIGMENTATION

The color of human skin is determined by a combination of several factors. The epidermis and the dermis contain the pigment carotene, and the hypodermis contains fat; both these substances contribute a yellow color to the skin. The red hemoglobin in blood circulating through the dermis contributes a pink tinge to the skin. A brown pigment, melanin, occurs in granular form in cells known as melanocytes. These cells are formed in the basal layer of the epi-

dermis and move outward to the stratum corneum. Dark-skinned persons have a great deal of melanin in the skin, while light-skinned persons have very little. Exposure to ultraviolet light increases the production of melanin; for this reason sunlight, which contains ultraviolet light, tans skin.

HAIR

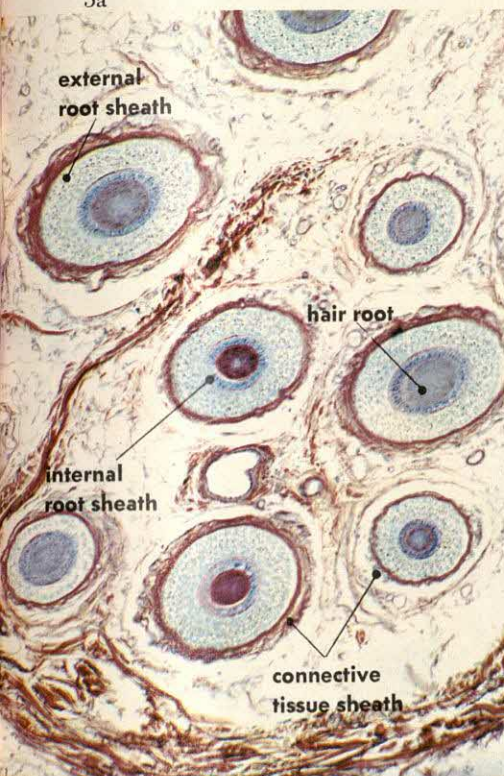
Hair has a basically protective function: the hair of the head, for example, provides warmth, and the eyelashes protect the eye from bright light and dust. A hair is a flexible filament that develops from a hair follicle. The follicle originates in

an invagination of the epidermis that extends into the dermis and sometimes into the hypodermis. A hair is made up of an external, visible hair shaft and an internal root that is buried in the skin.

The shaft of a hair consists of three layers: the innermost part, known as the medulla, is surrounded by cortex, which is covered by a cuticle. The medulla consists of soft keratin, and the cortex and cuticle consist of hard keratin. In the skin, the hair root is surrounded by three sheaths: the internal root sheath, the external root sheath, and the connective tissue sheath.

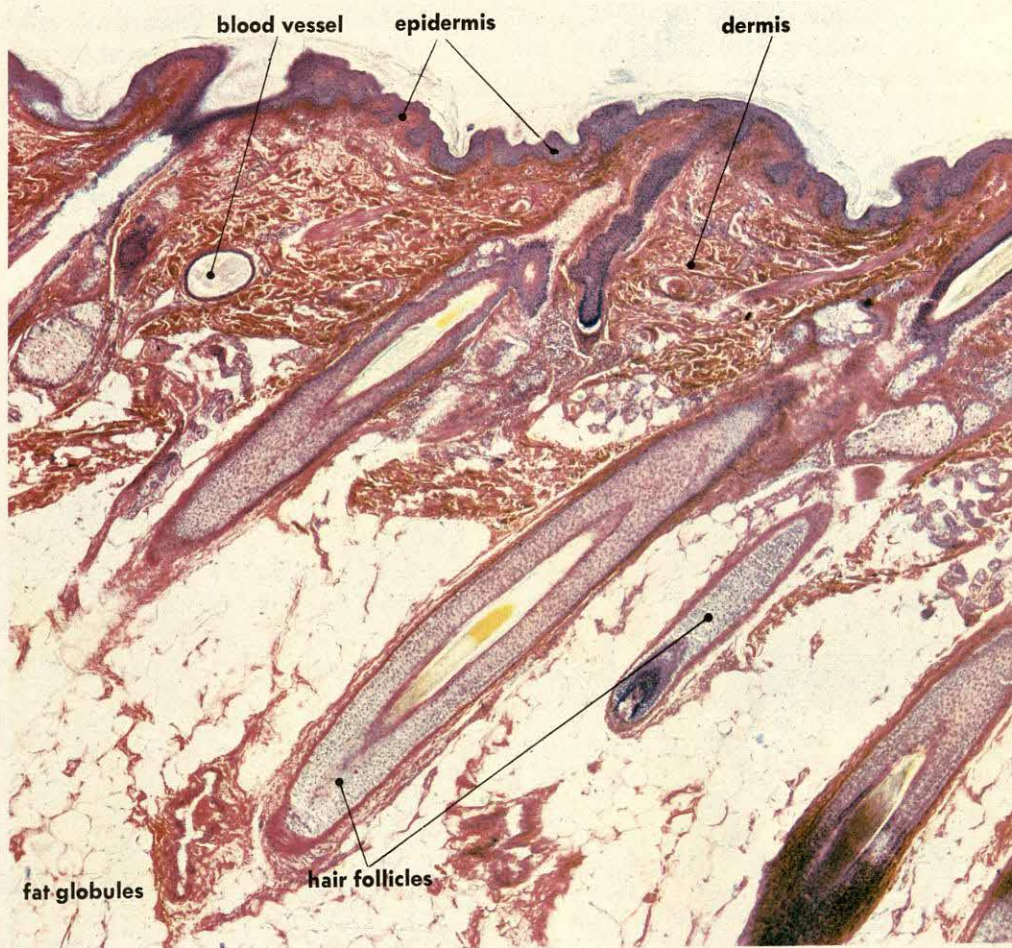
The deepest part of the hair root is rounded and forms the hair bulb. A pa-

5a



SECTION OF SCALP—Illustration 5a shows cross sections of hair follicles. (84 X, colored by Susa-Azan) Illustration 5b shows another section of scalp. Visible are the epidermis (the darker red zone), the dermis (in bright red), and the hypodermis (the lighter zone), which is rich in fat globules. Also visible are longitudinal sections of hair follicles, glandular appendages, and blood vessels.

5b



pillars of connective tissue occupies the center of the bulb. Associated with the hair follicle is the erector pili muscle, which straightens the hair and causes gooseflesh during highly emotional states and exposure to cold.

NAILS

The nails are formed mostly from the stratum corneum of the epidermis on the dorsal surfaces of the terminal portion of the fingers and toes. The nails are flat and squarish and consist of hard keratin. They rest on a nail bed composed of epidermis and dermis. Most of the nail is translucent and appears pink because of the blood circulating beneath it. The white, moon-shaped area at the base of the nail is known as the lunula. The nail root is buried under a flap of skin.

THE CUTANEOUS GLANDS

The sweat glands are scattered over the entire skin surface of the human body. They originate in the deepest part of the dermis, where they are coiled like a skein of yarn. From the dermis an excretory tubule leads to the surface, where the tubule opens in a sweat pore. Perspiration contains water, carbon dioxide, and several salts. There are two types of sweat glands: eccrine glands, which are the most common type and which excrete material removed from the blood; and apocrine glands, which occur in the armpits and genital areas and which excrete some of the cytoplasm of the cells of which they are constituted.

The sebaceous glands produce sebum, a fatty substance that waterproofs the skin. They are located in the dermis, and

their excretory ducts usually open into the necks of hair follicles.

The breasts are common to both sexes. They are paired, symmetrical cutaneous reliefs located in the anterior thoracic region. They mark the presence of the mammary glands in the subcutaneous tissue. The mammary glands are modified sweat glands of the apocrine type. At the center of the breasts are the nipples, projections with wrinkled surfaces surrounded by a more or less intensely pigmented surface, the aureole. At the tips of the nipples are the openings of the lactiferous pores, which are the external openings of the excretory ducts of the mammary glands. In females who have recently given birth, the mammary glands secrete milk. It is probable that in ancestral mammals both sexes participated in nursing the young.

THE MUSCLES

general characteristics;
muscles of the face and neck

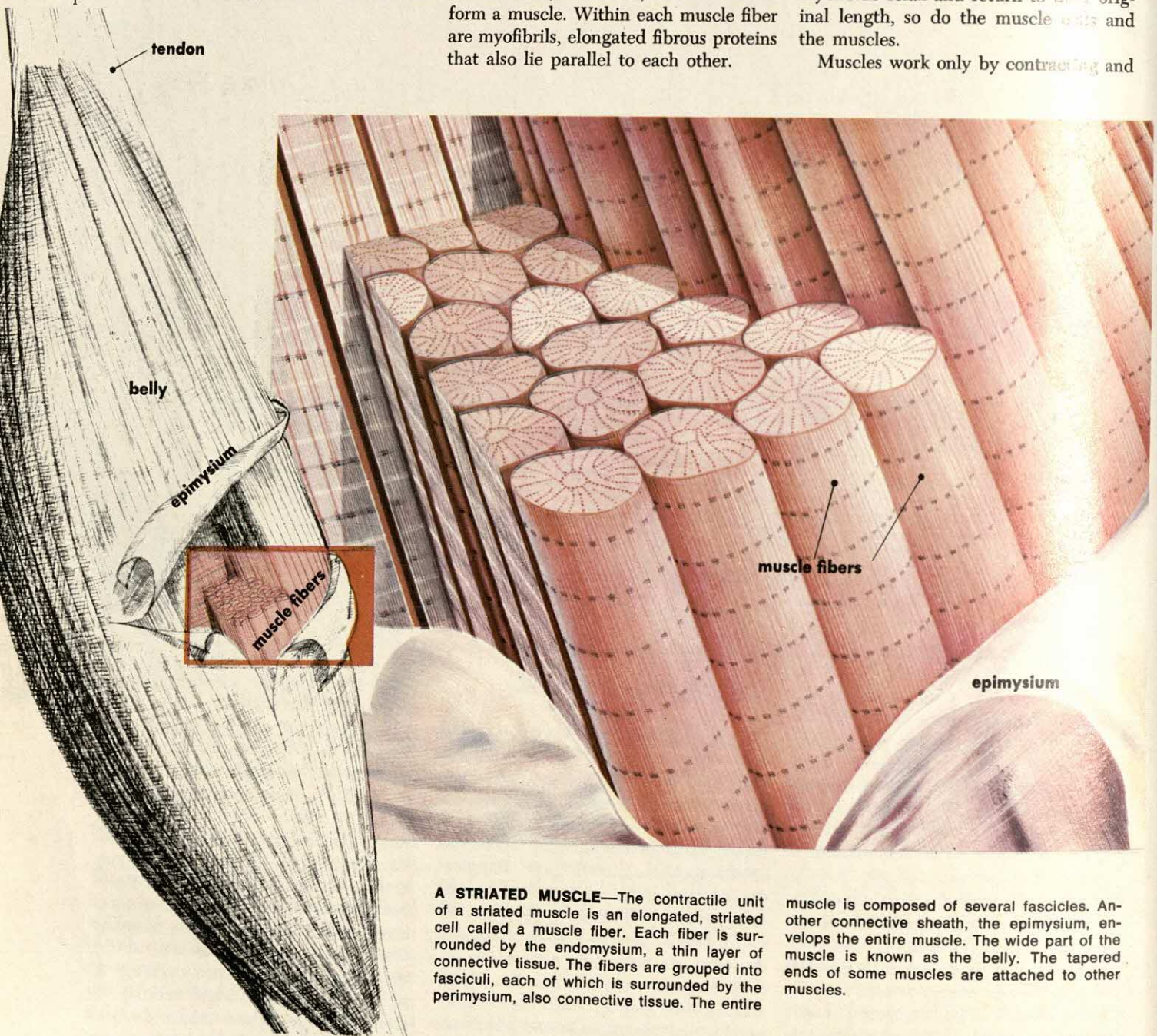
All but the most primitive of animals are dependent on muscles for movement. The muscles are used not only in locomotion—walking, swimming, or flying from one place to another—but in other voluntary movements, such as smiling or frowning, and in involuntary actions, such as the

peristaltic movements of the intestine and the beating of the heart.

Muscles consist of elongated cells called muscle fibers. The long axes of the muscle fibers lie parallel to each other within each muscle. The muscle fibers are united into fasciculi, or bundles, several of which form a muscle. Within each muscle fiber are myofibrils, elongated fibrous proteins that also lie parallel to each other.

A muscle functions by virtue of the contractile properties of its myofibrils—which means “little muscle threads.” When these contract, they become shorter and thicker; this action shortens the muscle cells and therefore the muscle. When the myofibrils relax and return to their original length, so do the muscle cells and the muscles.

Muscles work only by contracting and

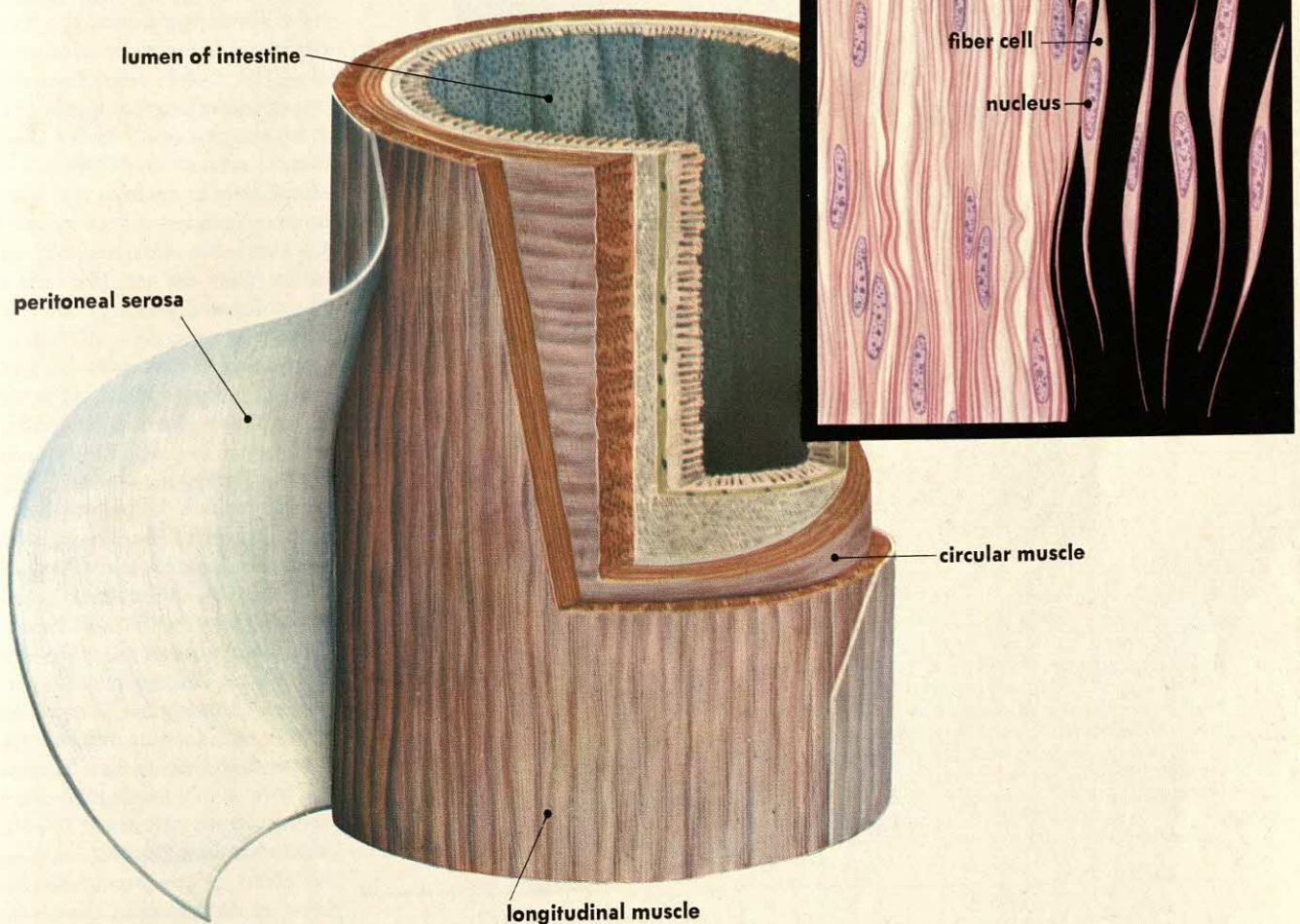


A STRIATED MUSCLE—The contractile unit of a striated muscle is an elongated, striated cell called a muscle fiber. Each fiber is surrounded by the endomysium, a thin layer of connective tissue. The fibers are grouped into fasciculi, each of which is surrounded by the perimysium, also connective tissue. The entire

muscle is composed of several fascicles. Another connective sheath, the epimysium, envelops the entire muscle. The wide part of the muscle is known as the belly. The tapered ends of some muscles are attached to other muscles.

SMOOTH, INVOLUNTARY MUSCLE—Smooth muscle is present in the intestinal wall and in other visceral organs. The contraction of the involuntary muscles changes the shapes of these organs. When the circular muscles con-

tract in a particular section of intestine, that section constricts. When the longitudinal muscles contract, that section returns to its original shape. The alternating action of these two sets of muscles produces intestinal peristalsis.



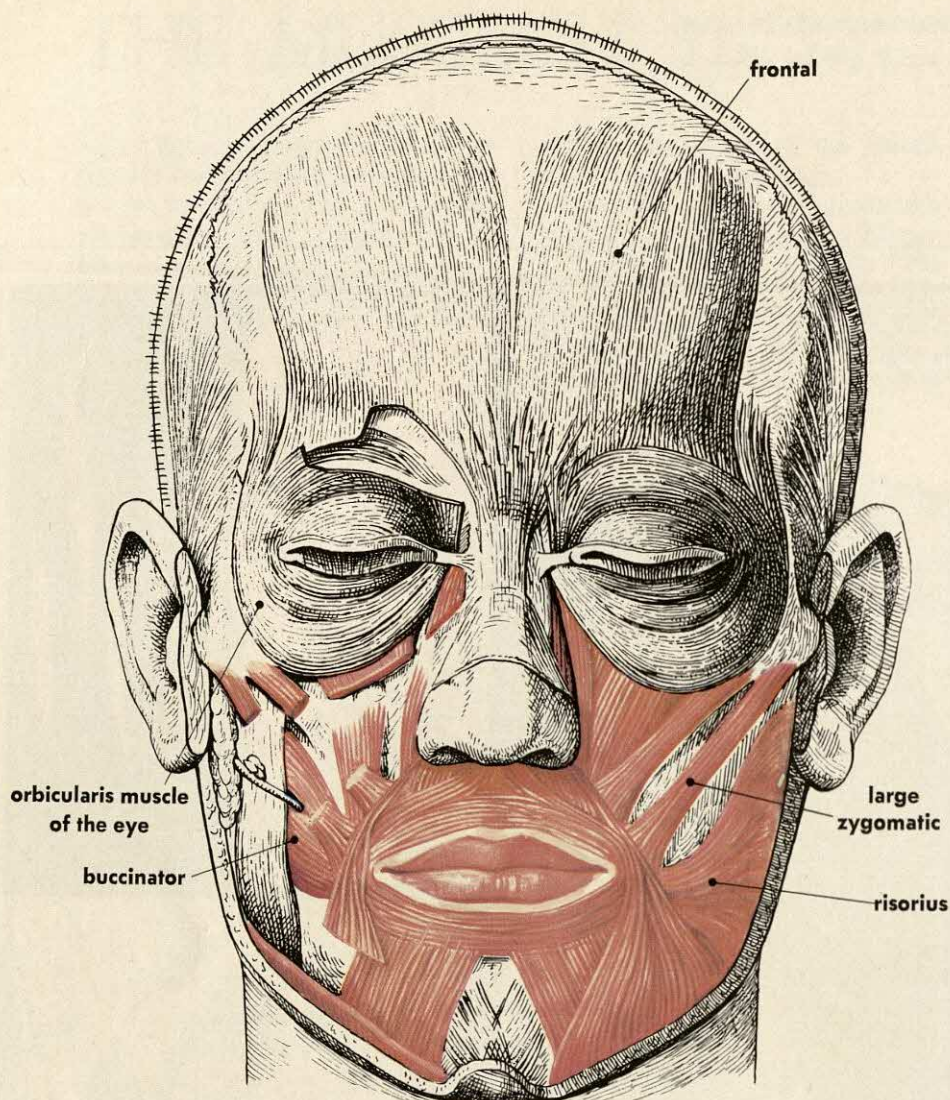
do not exert any effect when they relax. Muscles occur in pairs or sets that have opposite effects; for instance, contraction of the biceps muscle, which extends from shoulder to elbow and lies toward the inside of the upper arm, bends the arm at the elbow. Contraction of the triceps muscle, which also extends from shoulder to elbow but lies toward the outside of the arm, straightens the arm. The circular muscles and longitudinal muscles of

the intestine likewise have opposite effects: the circular muscles constrict the intestine and the longitudinal muscles widen it.

In addition to its muscle cells, a muscle contains connective tissue, blood capillaries, and nerve endings. The connective tissue surrounds the entire muscle; each fasciculus is surrounded by connective tissue, and so is the individual cell. The blood capillaries bring to actively

contracting muscles the food and oxygen that they require in great quantity. The capillaries also remove the waste products of cell metabolism. Motor end plates, the flattened endings of motor nerve fibers, are in close contact with the muscle fibers to which they transmit stimuli.

Muscular contraction occurs when the muscle receives a stimulus from a motor nerve. If the muscle receives a single short nerve impulse, it contracts for a



FACIAL MUSCLES—The muscles of the head are subdivided into two groups: the facial muscles and the muscles of mastication. The facial muscles are also known as the muscles of expression, because their location around the facial orifices and the arrangement of their fibers control facial expression. Among these are the occipital and frontal muscles, which by contracting wrinkle the brow. The fibers of

the risorius muscle lie horizontally directed toward the corners of the mouth. When this muscle contracts, the lips are drawn toward the sides of the face, modifying the expression of the mouth. The buccinator, the major cheek muscle, is important in chewing and in blowing. The orbicularis oris, which surrounds the mouth, closes the lips.

brief period of time and then relaxes. If the muscle receives impulses at intervals shorter than the duration of its contraction, relaxation does not occur, and the muscle goes into a state of tetanus, or continuous contraction.

Muscle tone is a phenomenon similar to the tetanus response. A few muscle fibers in a muscle are always in a state of contraction, the fibers contracting and relaxing in turn.

TYPES OF MUSCLES

The three main types of muscles are skeletal (striated) muscle, smooth muscle, and cardiac muscle. Skeletal muscles are

attached to the bones of the skeleton or to connective tissue, and they produce movements of the arms, legs, and face. Their cylindrical, tapering muscle fibers are striped by dark and light crossbands. There are several flat nuclei arranged in the periphery of each cell. Skeletal muscles are served by the central nervous system; and, because they are under the control of the will, they are called voluntary muscles. Skeletal muscles are quick to contract and to relax, usually requiring no more than 0.1 second for a complete cycle. Steak, pork chops, and the white and dark meat of chicken are examples of skeletal muscle.

Smooth muscles control automatic, in-

voluntary processes in the body. They are not attached to bones but are part of many internal organs. In the digestive system, they grind and churn food and move it along the length of the digestive tract. Blood vessels and the urinary bladder are other organs with smooth muscles. The muscle cells of smooth muscles are elongated, tapering cells that have no striations and occur in flat sheets. In the central area of each cell is a single nucleus. Smooth muscles are served by the autonomic nervous system, and they contract and relax automatically as the need arises. They are not under the control of the will, and therefore they are called involuntary muscles. Much slower to respond than skeletal muscles, smooth muscles may require from three seconds to three minutes to contract and relax.

Cardiac muscle, the muscle of the heart, is striated, but it is involuntary muscle, which keeps the heart beating automatically. The short cells are arranged in long rows and have blunt ends that abut on the ends of adjacent cells. Because some of the cells branch, the entire system of cells forms a network. Each cell has one or two ovoid nuclei near its center. The response of cardiac muscle is faster than that of smooth muscle but slower than that of skeletal muscle.

There is no fixed rule regarding the nomenclature of muscles. Some of their names are based on the number of their insertions, or attachments to the movable bone, as, for example, the biceps muscle, which has two insertions, and the triceps muscle, which has three insertions. Muscles can be named for their shapes—as, for example, the deltoid muscle, which is triangular. Many muscles are named for the bones into which they are inserted.

MUSCLES AND MOVEMENT IN THE ANIMAL KINGDOM

Movement is common to nearly all animals. Even though some of them do not have true muscles, they do have analogous structures. In the protozoa, which are single-celled animals, movement may be by hairlike projections called flagella (if they are relatively long) or cilia (if

they are short). These structures contain fibrous contractile proteins that contract and relax much like the myofibrils of muscle cells, causing the flagella or cilia to lash about and propel the animal through the water in which it lives. The amoebas, which have no external organelles of locomotion, move by means of their pseudopodia, temporary projections formed by the flowing of cytoplasm within the cell. This movement of cytoplasm is caused by contraction and relaxation of the proteins it contains.

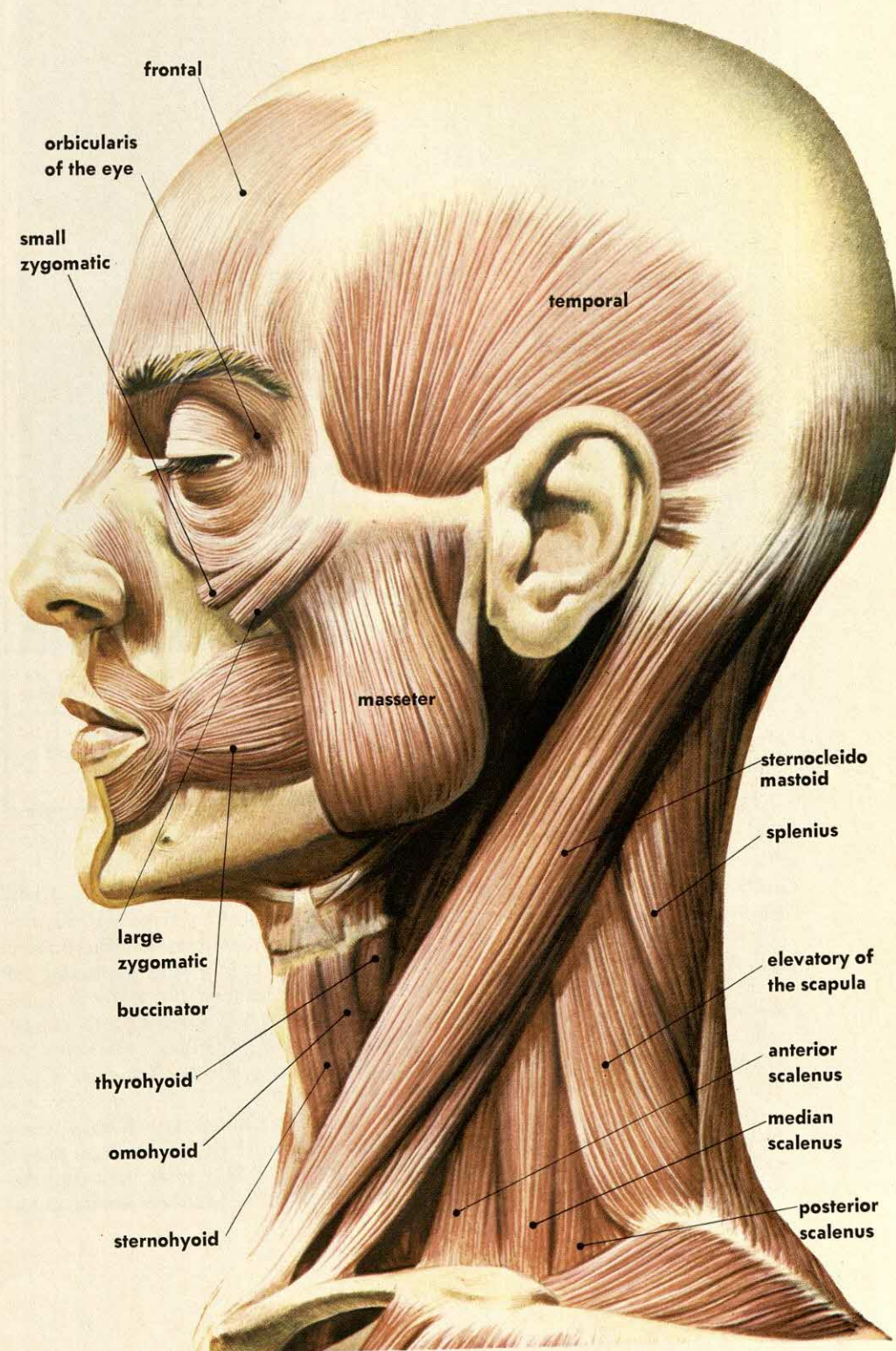
The coelenterates, which include *Hydra* and the jellyfish, are multicellular animals with only primitive differentiation of cells. They have no specialized muscle systems, but many of the cells have contractile fibers near their bases. These are served by a nerve net that coordinates the contractions of the cells and thus controls the movements of the animal.

The flatworms, such as planaria, and the segmented worms, such as the earthworms, have circular muscles that lie transversely in the animal and encircle some or all of its internal organs. Longitudinal muscles lie parallel to the long axis of the animal. These two types of muscle have antagonistic effects much like the circular and longitudinal muscles of the human intestine.

The body of the earthworm is divided into segments called metameres. Many of these segments are identical, each containing its own muscle segment, nerves, and blood vessels. Many of the more highly evolved animals, including the vertebrates, are metameric. The vertebrates, however, display their metamerism primarily in their embryonic stages; a vertebrate embryo, for example, contains several pairs of segments called somites. As the embryo develops, part of each somite forms muscle tissue. Each vertebra of the spinal column arises from a pair of somites. A pair of spinal nerves branch from the spinal cord to serve the muscles produced by each pair of somites. Subsequent growth obscures the segmentation, so that an adult vertebrate shows none of the external rings that characterize an earthworm.

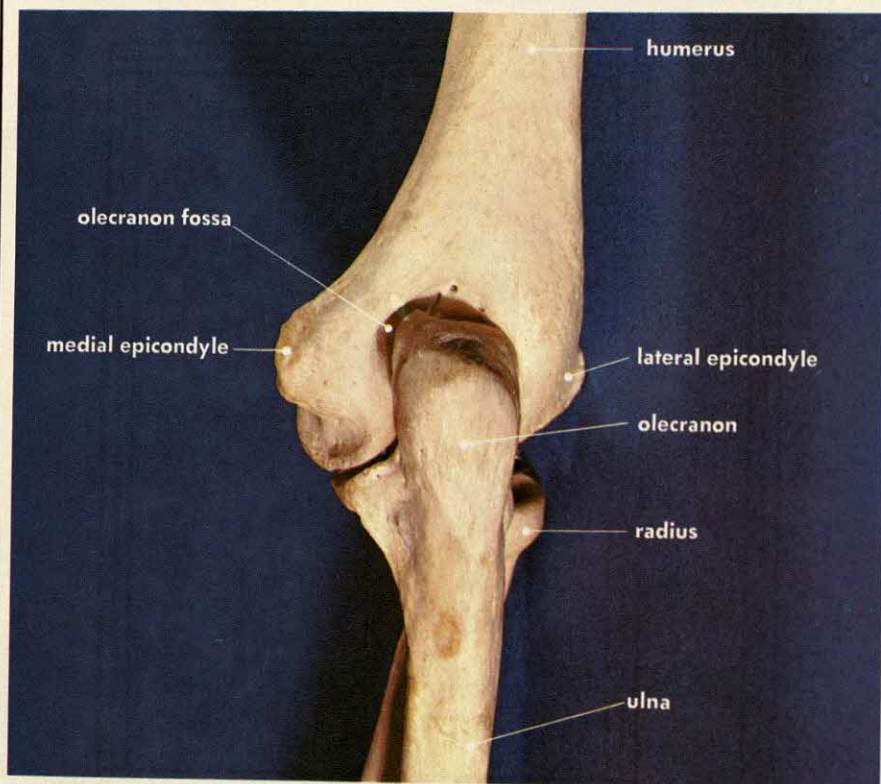
THE MASTICATORY MUSCLES AND THE NECK MUSCLES—The masticatory muscles are skeletal muscles. The masseter and the fan-shaped temporal muscle are masticatory muscles that close the jaw. Among the neck muscles is the sternocleidomastoid muscle, which as its name indicates, has insertions on three different bones, the sternum, the clavicle, and the mastoid process. This muscle rotates the head, turning it toward one shoulder and away from the other. If the head remains immobile, the sternocleidomastoid serves as an inspiratory muscle by acting on

the clavicle and sternum. The four subhyoid muscles, sternohyoid, sternothyroideus (not shown), omohyoid, and thyrohyoid, regulate the movement of the thyroid cartilage and the hyoid bone. The scalenus muscles raise the first and second ribs in respiratory movements and bend the neck. Other neck muscles, not shown here, are the suprahyoid muscles, which regulate the movement of the hyoid bone, the jaws, and the tongue. The platysma is located below the epidermis; it extends from the clavicle to the mouth.



THE SKELETON | the joints and the skull

1



DORSAL VIEW OF THE ELBOW—This joint unites the upper arm and the lower arm. It is made up of two different diarthroses, one between the humerus and the ulna, and the other between the humerus and the radius. The shapes of the bones on either side of the

joint are complementary: their forms fit perfectly. In a living person, the cavity between the bones contains synovial fluid, a dense liquid that lubricates the surfaces and nourishes the cartilage. The entire joint would be enclosed by a fibrous capsule.

bones are examples.

And finally, a diarthrosis is a joint that permits free movement of the two bones. The ends of the bones are covered by cartilage, but there is a cavity between them. A capsule of fibrous material encloses the ends of the bones and the cavity. The sensitive and vascular inner lining of the capsule secretes a liquid, the synovial fluid, that acts as a lubricant, permits easy movement, and nourishes the cartilage.

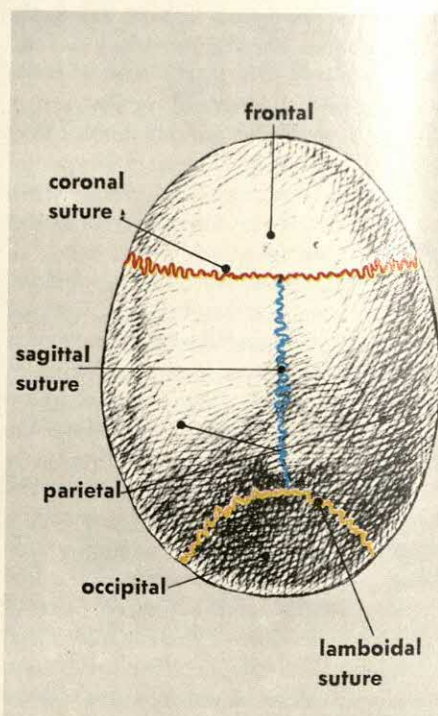
Examples of diarthrosis are the hinge joints of the fingers that permit movement in only one plane, the pivot joints of the elbows that permit pivoting movements, and the ball-and-socket joints of the shoulders and hips that permit rotation of the arms and legs in many different planes.

2

CRANIUMS OF AN ADULT AND AN INFANT

The cranium is made up essentially of eight bones. Four of these—the frontal, ethmoid,

a



The skeleton of the human body is a system of several functions. Its bones and cartilage form a sturdy framework that supports the softer and weaker parts of the body. At the joints the bones articulate with each other; many of these articulations are movable joints that permit agile body movements. Some bones protect vital internal organs; the ribs and the sternum (breastbone) form a cage around the heart and lungs, and the skull shields the brain. In adults, all the red blood cells and platelets and most white cells are formed in the marrow of some (but not all) bones.

JOINTS

A joint, which is an articulation of two bones, is composed of three types: synarthroses, amphiarthroses, and diarthroses. A synarthrosis is a joint permitting no movement between the bones it joins. The material between the bones may be fibrous tissue or cartilage; the joints between the cranial bones, for example, are synarthroses.

An amphiarthrosis is a slightly movable joint, in which the bones are joined by cartilage. The joints between the vertebrae and the joint between the pubic

THE BONES

A highly specialized form of connective tissue, bone is made of branching cells in an intercellular substance. Its hardness is the main characteristic that sets it apart from other kinds of supporting tissue. This quality results from a form of calcification—the deposition in a soft organic matrix of a complex mineral. The substance of bones is about half water and half solids. The composition of the solid matter in human bones includes the organic white fibrous tissue, which gives elasticity; calcium phosphate; calcium carbonate; calcium fluoride; magnesium phosphate; and sodium chloride. The organic tissue is impregnated with the mineral salts to such a high degree that when the tissue is removed or disintegrates, the

bone keeps its shape. If the mineral substances are removed, however, the bone can be bent easily.

Bones may be classified into four groups on the basis of shape: long bones, those of the arms and legs; short bones, those of the wrists and ankles; flat bones, such as those of the skull; and irregular bones, such as the vertebrae. A total of 206 bones constitutes the human skeleton.

Part of each bone is dense and heavy and part is spongy, giving the greatest possible strength for size and weight. The long bones of the arms and legs have a lengthwise hollow in the shaft, which provides lightness without appreciable loss of strength.

Bones are formed, both in fetal life and afterward, from transformation of

connective tissue. Most bones develop in the embryo from a cartilaginous "model" that is about the same shape as the bone that will take its place when the cartilage cells are replaced by osteoblasts, the bone-forming cells.

The periosteum, a thin membrane, covers the bones except at the joints, where there is a layer of cartilage. Nerves and blood and lymph vessels lie along the periosteum before entering small canals in the bone.

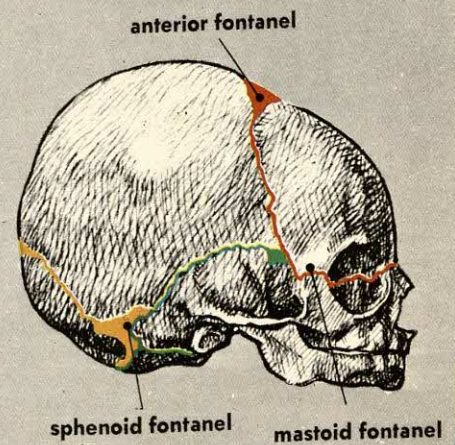
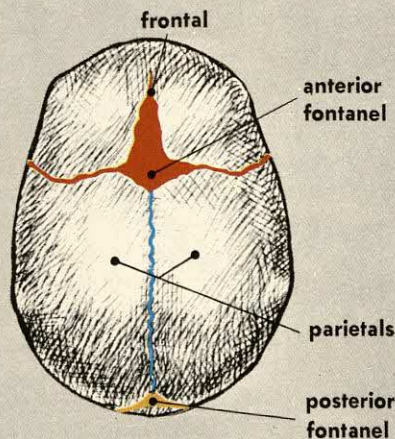
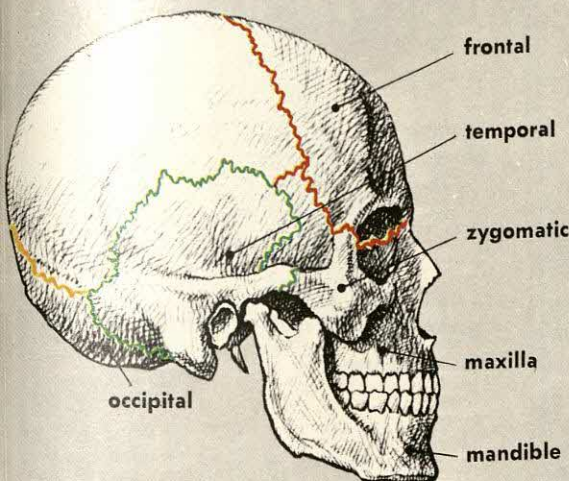
THE SKULL

The protective function of bones becomes especially apparent in a study of the skull. The skull consists of two parts: the cranium and the bones of the face. The cranium has eight flat bones fused

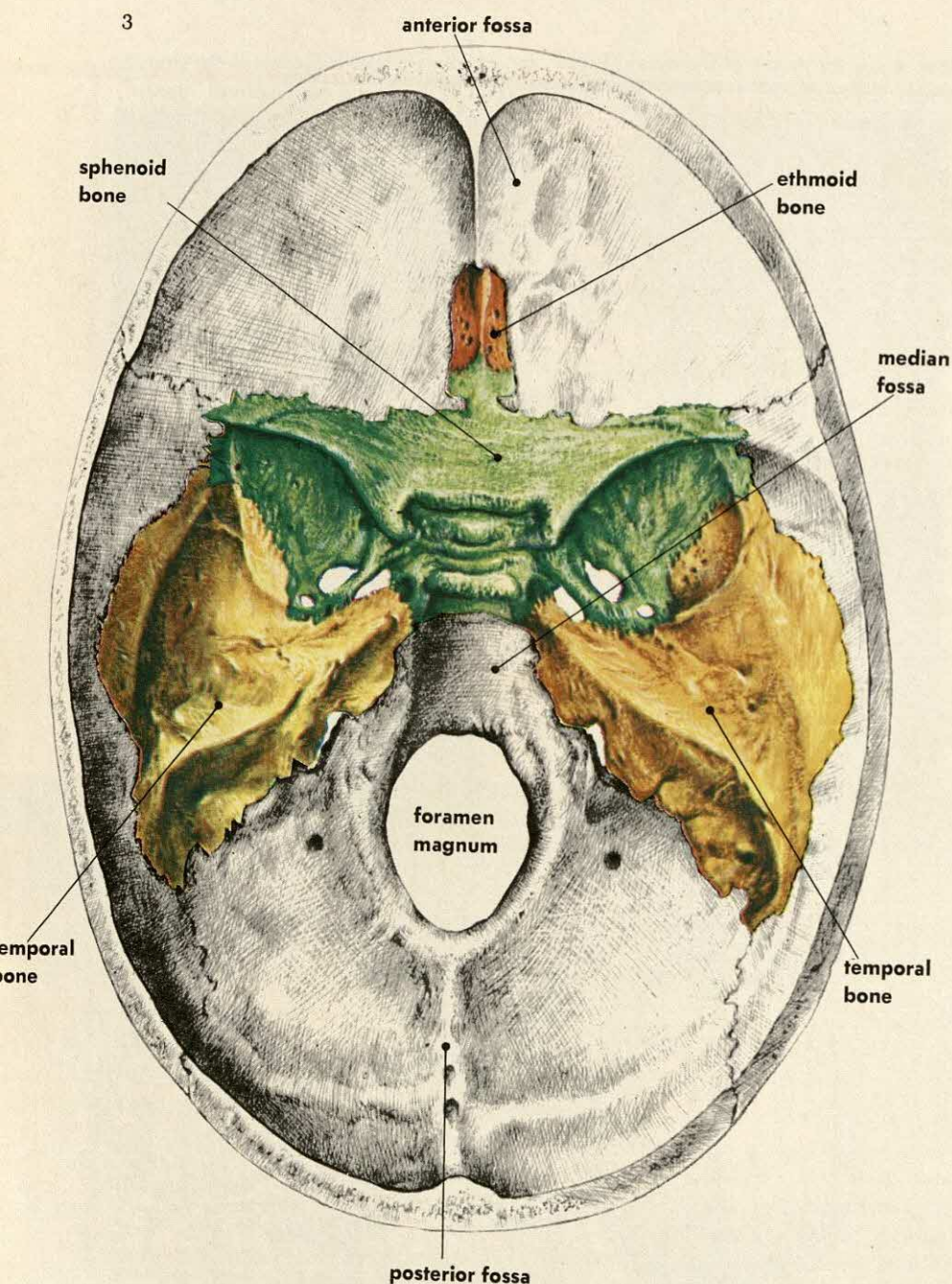
sphenoid, and occipital—are single and median. Two of them—the parietal and temporal—are paired on the sides of the cranium. Illustrations 2a and 2b show an adult cranium with its sutures, the fixed junctions of the head bones. Illustrations 2c and 2d show the

cranium of an infant, in which the fontanels are evident. These spaces are covered with fibrous tissue.

d



3



BASE OF THE CRANIUM AS SEEN FROM ABOVE—The cranium has three depressions: the anterior, the median, and the posterior fossae. These depressions support different parts of the brain. The anterior fossa holds

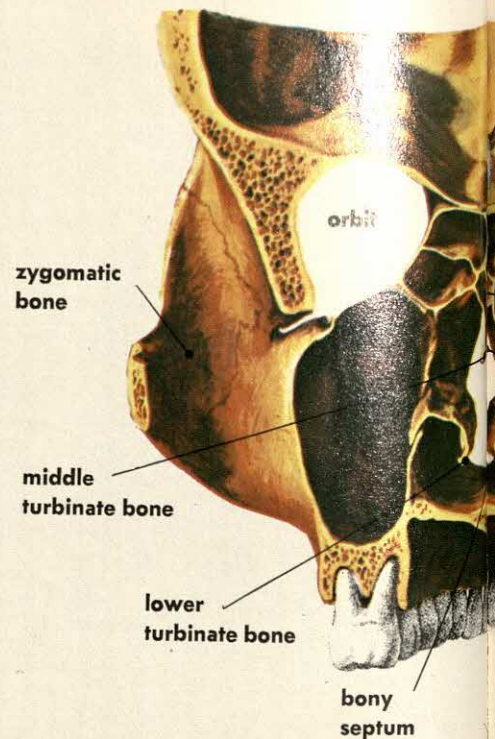
the frontal lobes; the median fossa holds the temporal lobes; and the posterior fossa holds the cerebellum. The posterior fossa also contains the foramen magnum.

into one rigid structure that almost completely surrounds the brain. The sutures between the individual bones are wavy, the lobes of adjacent bones interlocking to prevent slippage. When viewed from above, four cranium bones are visible; the frontal bone, two parietal bones, and the occipital bone. These bones protect the brain from mechanical injury from above and from the sides. The lower part of the brain is protected by the edges of these bones, which curve under the four other bones: the ethmoid bone, the sphenoid bone, and two temporal bones.

So well put together are the eight cranial bones that the only openings are those that allow for the passage of blood vessels and nerves through which the brain exchanges materials and nervous

THE NASAL CAVITIES

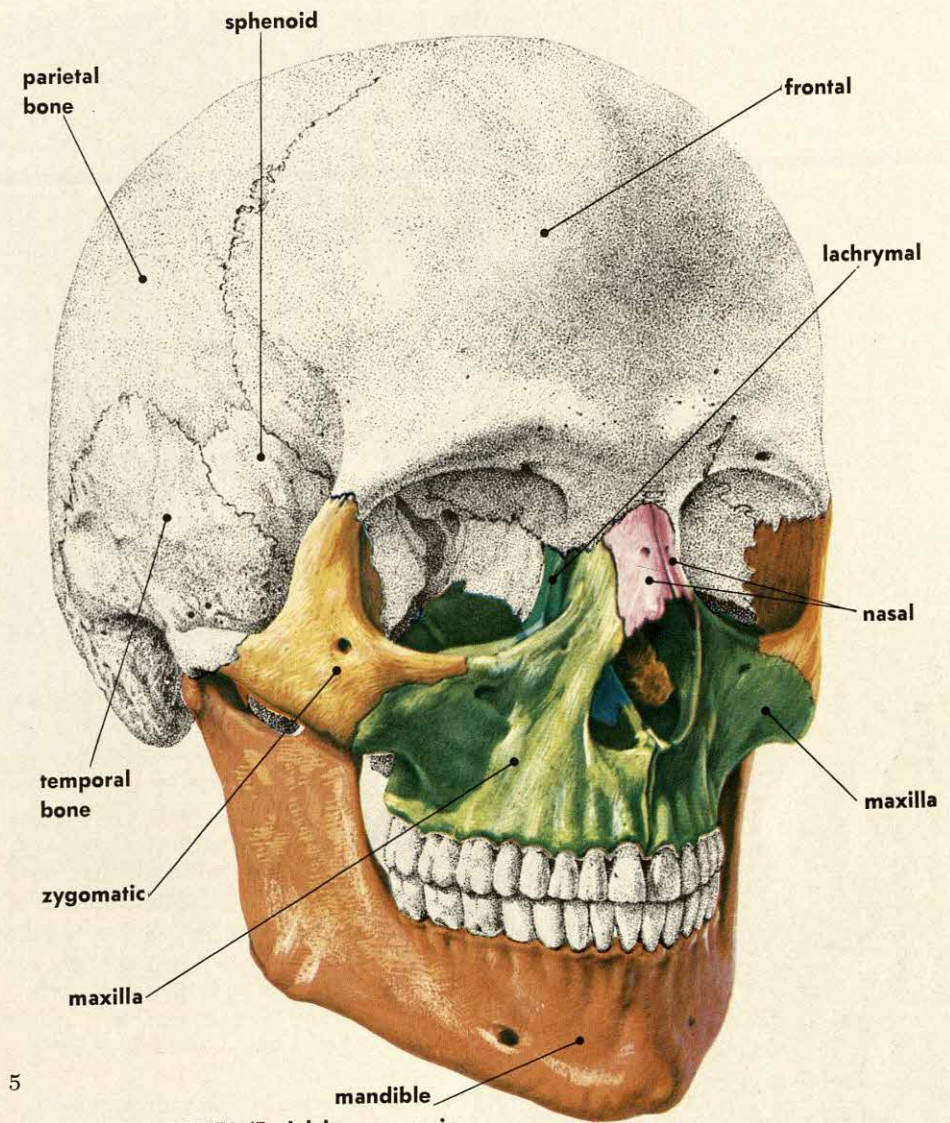
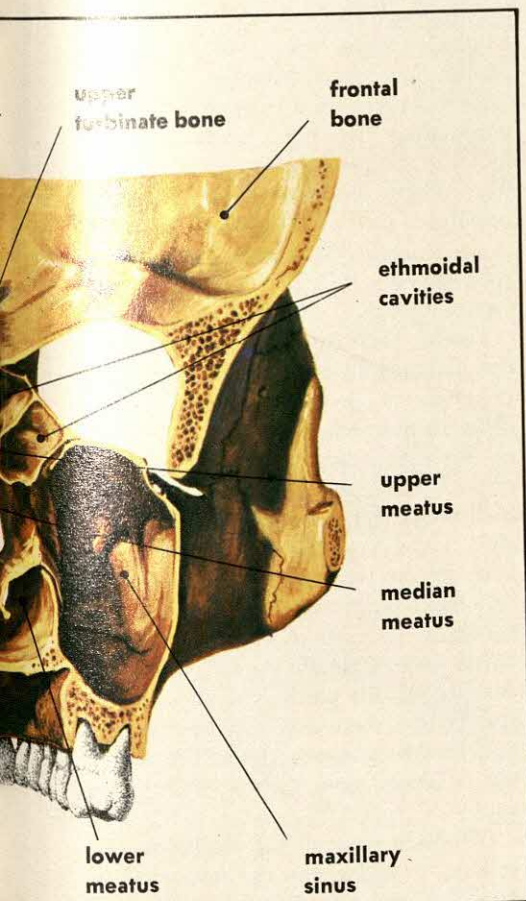
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stimulations with the rest of the body. One of these openings is the foramen magnum, through which the brain connects with the spinal cord.

There are 14 facial bones. One of them, the mandible, constitutes the entire lower jaw; the remainder form the rest of the face. Two maxillary bones form the upper jaw and part of the palate, or roof of the mouth. Half of the teeth are carried by the maxillary bones, and half by the mandible.

Two zygomatic bones, which lie below and behind the eyes, form the cheek prominences. A pair of small nasal bones forms the bridge of the nose; the rest of the nose is supported only by cartilage. Two small lachrymal bones form part of the eye sockets; two palatine bones form the rear part of the palate and part of



5
THE FACIAL BONES (Facial bones are in color. Cranial bones are not colored.)

the nasal cavity; and the two inferior nasal concha (turbinate bones) are small twisted bones within the nose that support the nasal membranes. The vomer is the lower and posterior part of the nasal septum; the rest of the septum is comprised of cartilage.

The hyoid bone is a single, U-shaped bone of the head that belongs to neither the cranium nor the face. It lies below the tongue, and it articulates with no other bone but is suspended by ligaments from the temporal bones of the skull. Six other bones that do not articulate

with the skull are the small bones of each ear—these are the hammer, anvil, and stirrup in the middle ear.

In the adult human, the bones of the cranium fit neatly together, but at birth the bones are not fully formed. Membranous areas called fontanels, or “soft spots,” are present between the bones. These fontanels allow some movement of the cranial bones with reference to each other and allow the skull to accommodate itself to pressures experienced during passage through the birth canal. After birth the sutures gradually close.

PART 3

- 73 The Origin of the Planets
- 77 The Origin of the Elements
- 80 Life Invades the Earth

EARTH SCIENCE | a multifaceted discipline

Until recently, the earth scientist was usually pictured as a bearded, lonely man on top of a mountain, armed with geologic hammer, compass, and hand lens. Today, earth scientists can be found in scuba gear studying coral reef growth in Florida, in an airplane over Africa studying the Earth's magnetic fields, or on a ship in the Indian Ocean analyzing the dredgings of deep sea ooze. Tomorrow, they will surely be found on the moon and on Mars, mapping the frontiers of a new world.

What exactly does the earth scientist seek? He is, above all, interested in understanding the history, nature, and significance of the physical world in which he lives. In this first volume the reader will join with the scientist as he seeks to explain how the elements may have formed in the fiery interiors of stars ("The Origin of the Elements"), how a vast gas nebula gave birth to the planets of our solar system ("The Origin of the Planets"), and how life evolved on a sterile and hostile Earth ("Life Invades the Earth").

The diversity of these three introductory articles serves to emphasize the variety of background required for the professional study of earth science. For example, geophysicists investigating the origin of planets obviously require a fundamental understanding of physics, astronomy, and mathematics. These same geophysicists also turn their talents toward studies involving the shape of the Earth (geodesy), the nature of the Earth's gravity, magnetic, and electrical fields, the behavior and form of the oceans (oceanography) and the atmosphere (meteorology and aeronomy). Geophysicists also utilize their understanding of physical forces in studying earthquakes (seismology) and mountain building (tectonics).

In a similar manner, geochemists must appreciate and understand fundamental chemical behavior as they investigate such contrasting phenomena as how elements originate, how granite is formed

from a molten magma (volcanology), or how radioactive substances can reveal the age of rocks (isotope geochemistry). As they study such complex processes as the origin of petroleum and how minerals and rocks form (mineralogy and petrology), geochemists help in the search for economically valuable materials.

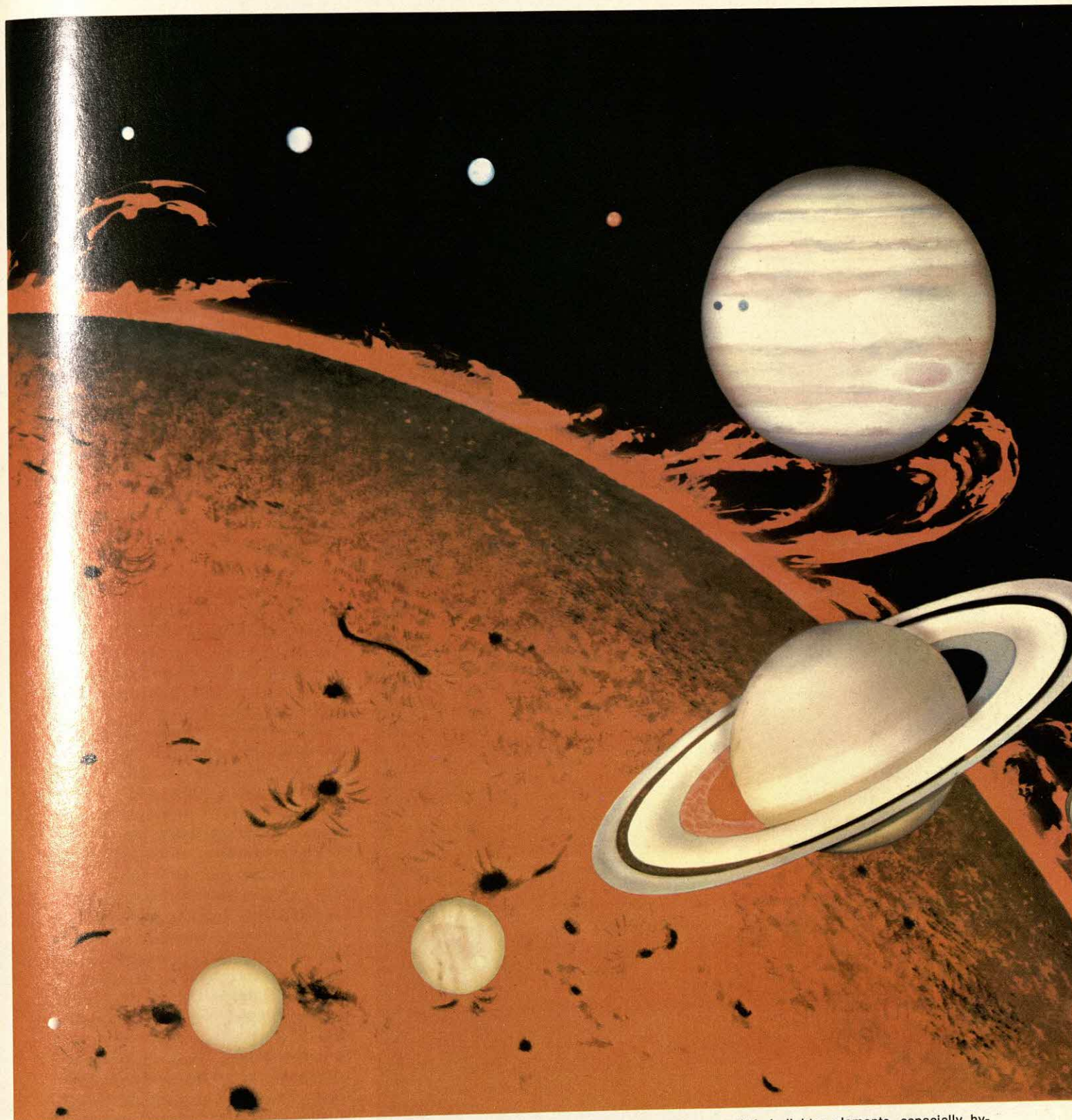
In addition to his background in physics and chemistry, the modern earth scientist is often an accomplished biologist. It is altogether reasonable that he must understand the behavior of today's organisms as he attempts to look back into time and answer the question of how life began and evolved on this planet. Such reconstruction of geologic history depends to a large extent on understanding the significance of fossils found in the geologic record (paleontology). These remnants of past life are a prime clue used by the geologic detective as he interprets the various patterns and environments of the far-distant past (stratigraphy).

Finally, these three introductory articles illustrate a basic truth of all science: the study of any physical phenomenon proceeds most efficiently if it is based on a thorough understanding of fundamental principles. Before we can truly understand how mountains grow, we must know how the planet itself was born. Before we can reproduce minerals and rocks in the laboratory, it may be necessary to understand how the elements were originally formed. Before we describe the life patterns of an organism that lived a mere million years ago, we may need to understand how life on this planet began more than a billion years ago.

Of course none of the articles in this volume, or elsewhere, can answer these questions precisely. Science is only now starting to speculate on possible theories. However, H. P. Berlage in a recent book, *Origin of the Solar System*, quoted an old Dutch proverb that seems especially appropriate here: *A good start is half the work.*



THE ORIGIN OF THE PLANETS | old and new theories



A DIFFERENCE IN DENSITY—The planets of the solar system can be designated as large and small. The large planets—Jupiter, Saturn, Uranus, and Neptune—have a chemical com-

position similar to that of the sun, inasmuch as they have retained the matter they had during their formation. The smaller planets—Mercury, the Earth, Venus, Mars, and Pluto—lost

most of their lighter elements, especially hydrogen and helium, and have become more dense than the larger planets.

Because astronomy is an observational science, the astronomer must base his ideas of the origin of the planets on their observed physical properties. The nature of Earth as a planet—its size, mass, and chemical composition—is relatively well known. The properties of other planets are less well known, but they are one of the most important clues in the formation of a theory of planetary evolution.

The following table gives the mass (as compared with Earth), the mean diameter (in miles), and the mean density (compared with that of water) of the planets and the moon.

Planet	Mass (Earth = 1.00)	Mean diameter (miles)	Mean density (water = 1.00)
Mercury	0.056	3,100	5.1
Venus	0.82	7,570	5.3
Earth	1.0000	7,927	5.52
Moon	0.0123	2,160	3.33
Mars	0.108	4,200	3.94
Jupiter	318.	88,700	1.33
Saturn	95.2	75,100	0.68
Uranus	14.6	29,000	1.56
Neptune	17.3	28,000	2.27
Pluto	0.06?	3,700?	4.?

Among the satellites in the solar system, the Earth's moon is unique. All other satellites are much smaller than their associated planet. Jupiter's large satellites, for example, are about the same size as the moon, yet the diameter of Jupiter is more than 11 times that of Earth. In every case except that of the moon, the parent planet provides the dominant gravitational force. In the case of the moon, the sun exerts a greater influence than does the Earth. The Earth-moon system is really a double planet and not a true planet-satellite system. Thus, astronomers might expect the moon's history to resemble that of the planets.

On the other hand, while the physical properties of the most distant planet, Pluto, are not well known, dynamical studies indicate that Pluto was probably formed as a satellite of Neptune. As a result, its history is quite different from that of the other planets.

A glance at the table shows clearly the

existence of two logical groups of planets. One, which includes Mercury, Venus, Earth (and the moon), and Mars, consists of planets with small diameters and high densities. These are called the terrestrial planets. The other group, the giant or Jovian planets, includes Jupiter, Saturn, Uranus, and Neptune. These planets are much larger than the terrestrial planets but are much less dense. Saturn's density is so low that it would actually float on water if it could be placed in a large enough tub. The large, low-density planets contain a much higher proportion of light elements such

Any theory of the origin of the planets must also explain why the sun, which has almost all the mass in the solar system, has less than 2 percent of its angular momentum—while Jupiter and Saturn, with less than 0.1 percent of the mass, have over 80 percent of the angular momentum.

A further dynamical observation that must be explained is the great regularity of planetary motion. The planets all revolve about the sun in the same direction in nearly circular orbits. Furthermore, most planets rotate on their axes in the same sense (west to east) as their revolution about the sun.

THE ORIGIN OF THE PLANETS

A theory of the origin of the planets must have two principal parts. The first, describing how the planetary material originated, must explain the observed features of planetary motion. The second part, describing how the planets condensed from this material, must account for the physical nature of each of the planets.

HISTORICAL THEORIES OF THE ORIGIN OF THE PLANETS

Theories of the formation of the planets can be divided into two main classes, nebular and tidal. The nebular theories explain the planets as condensations in a contracting gas cloud that formed the sun. Early researchers in this field included Descartes, Kant, and Laplace. The nebular theory was long in disfavor because it did not resolve the angular momentum problem. If the gas cloud that formed the sun was rotating at the speed of Jupiter's motion when the cloud was the size of Jupiter's orbit, the sun should be rotating much faster than it does and should contain most of the angular momentum of the solar system.

The tidal theory explains the planets as condensations in a filament of material pulled off the sun by another star passing by at close range. The angular momentum problem is thereby solved, since the planets would have received their angular momentum from the passing star and not from the sun. However, this theory,

as hydrogen and helium than do the smaller, high-density planets. The percentage of light elements in the Jovian planets is very close to that in the sun. Any theory of the formation of the planets must explain why the composition of the Jovian and terrestrial planets is so dissimilar.

DYNAMICAL PROPERTIES OF THE SOLAR SYSTEM

Another important clue to the origin of the planets is the distribution of angular momentum in the solar system. Most of the angular momentum is contained in the Jovian planets. Jupiter has 59.6 percent of the total angular momentum of the solar system, Saturn has 24.4 percent, Uranus 5.3 percent, and Neptune 8.2 percent. Of the remaining 2.5 percent, Pluto has 0.4 percent, the terrestrial planets together 0.2 percent, and the sun the remaining 1.9 percent.

which has difficulty explaining why the planetary orbits are so nearly circular, has not survived detailed quantitative analysis. The tidal theory is currently in disfavor.

Either theory must then be combined with a condensation mechanism explanation for the planets themselves. Possibilities include planets forming as gas clouds and then solidifying, planets forming as small subplanets that then combine, and more complicated gravity-density models.

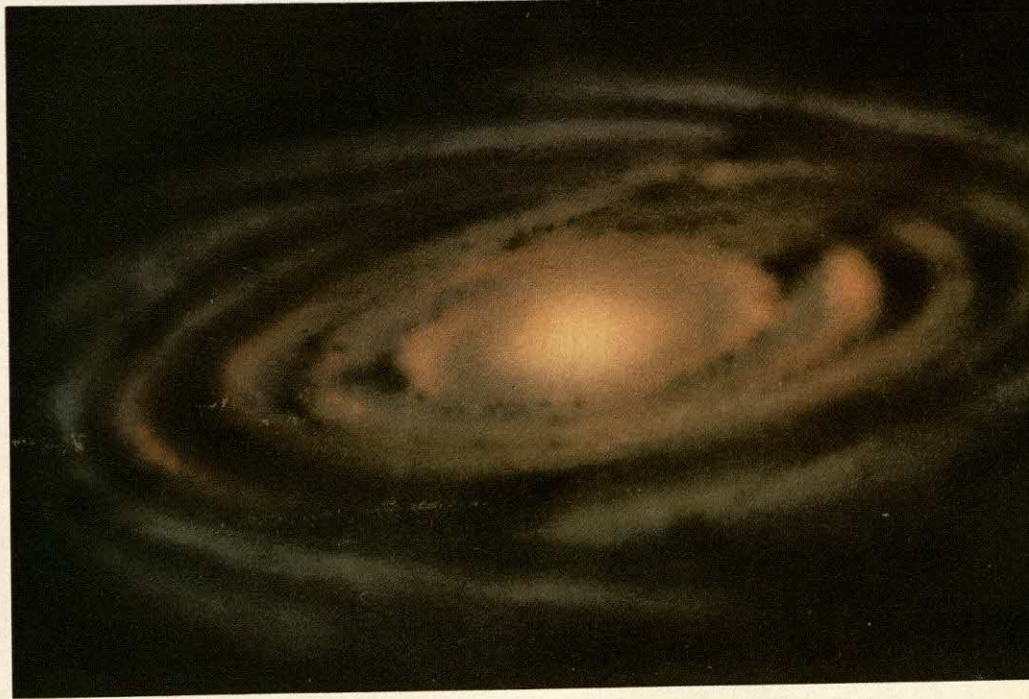
MODERN THEORIES

Most modern theories of the formation of the planets are variations of the nebular hypothesis. The revival of this theory is due in large part to the German physicist C. F. von Weizsäcker, who reintroduced the idea of vortices—an idea originally due to Descartes—and showed in detail how the planets could condense from a nebular cloud. The distribution of matter in the cloud can explain the mass distribution in the solar system. The higher temperatures near the sun explain why the terrestrial planets have lost most of their light elements.

The problem of angular momentum is solved through the medium of magnetic fields. During the formation of the planets, the material in the contracting cloud probably was tightly coupled to the sun by magnetic fields. This phenomenon would cause a transfer of angular momentum to the planets and can thus account for present observations.

IS THE SOLAR SYSTEM UNIQUE?

If the nebular hypothesis is correct, it is reasonable to expect that many stars have planetary systems. There is evidence for this view; for example, the nearby star, Barnard's star, has a companion object that is only slightly more massive than Jupiter. It has been found, in fact, that about half of the nearest stars have companion objects from about the mass of Jupiter to 30 times its mass. The existence of satellite systems of major planets in the Earth's solar system suggests a widespread planetary formation.

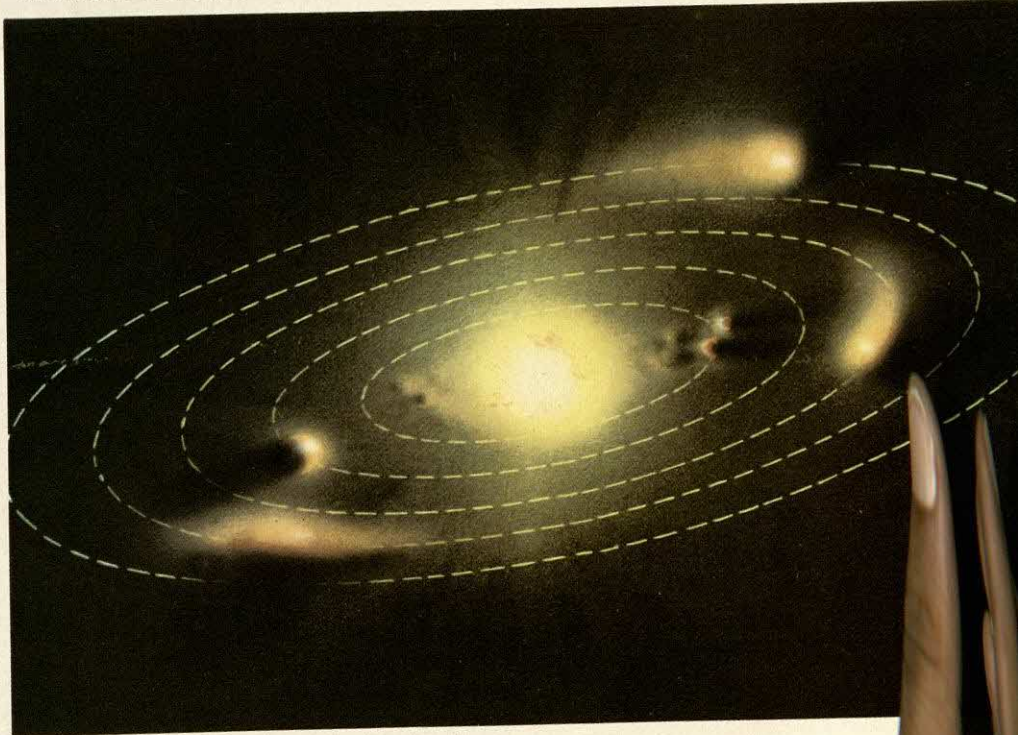


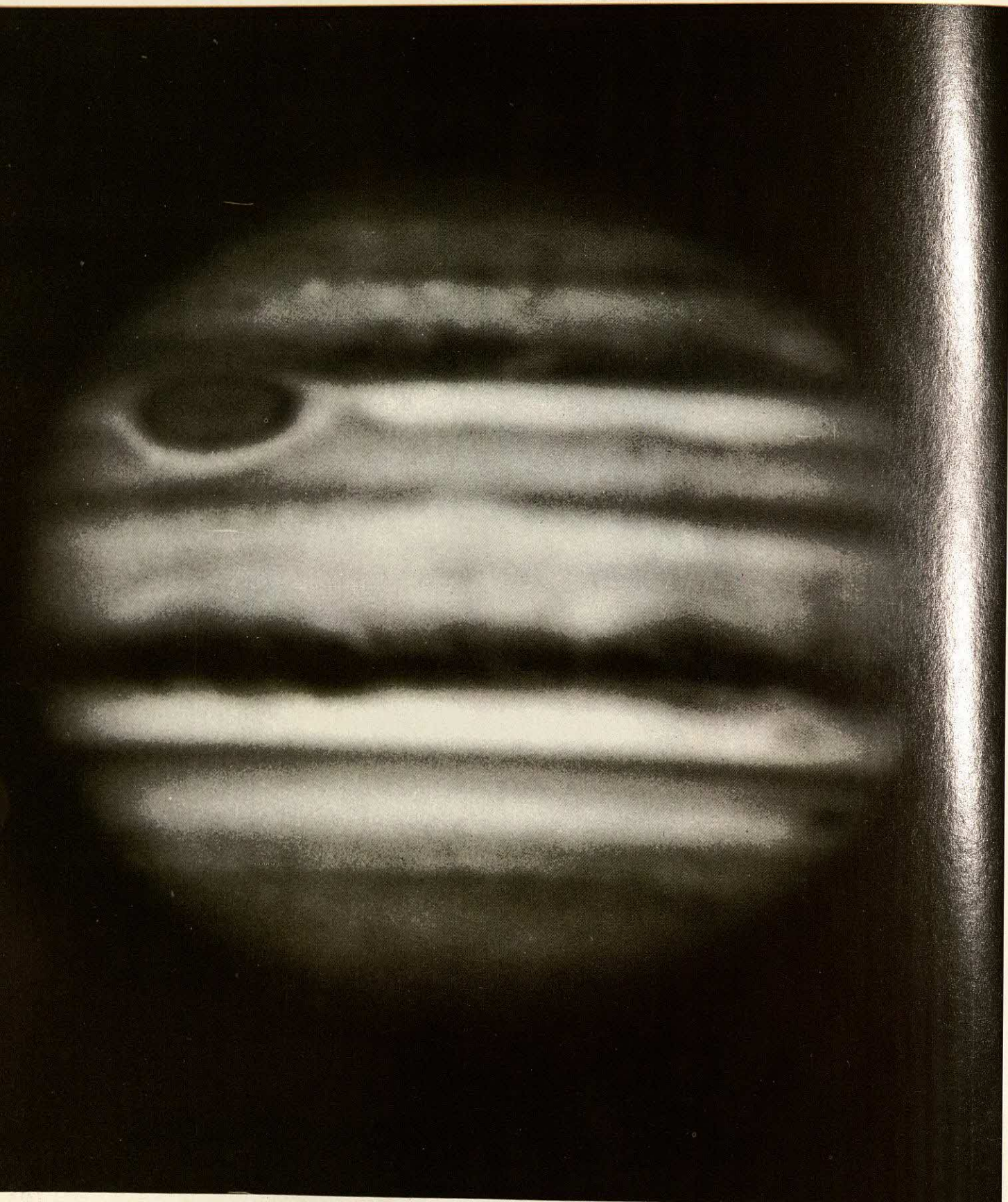
THE NEBULAR HYPOTHESIS—Illustration 2 shows how the planets may have formed from the cloud that contracted to form the sun. At the left, large and small regions are contracting from the rotating cloud; they are coupled to the sun by magnetic fields extending through the nebula.

Illustration 3 shows the situation somewhat

later. Much of the matter has condensed into the sun and the planets. The rest has escaped from the solar system. The small planets near the hot sun are unable to retain much of their lighter elements and have a high density. The planets far from the sun retain the light elements and have a much lower density.

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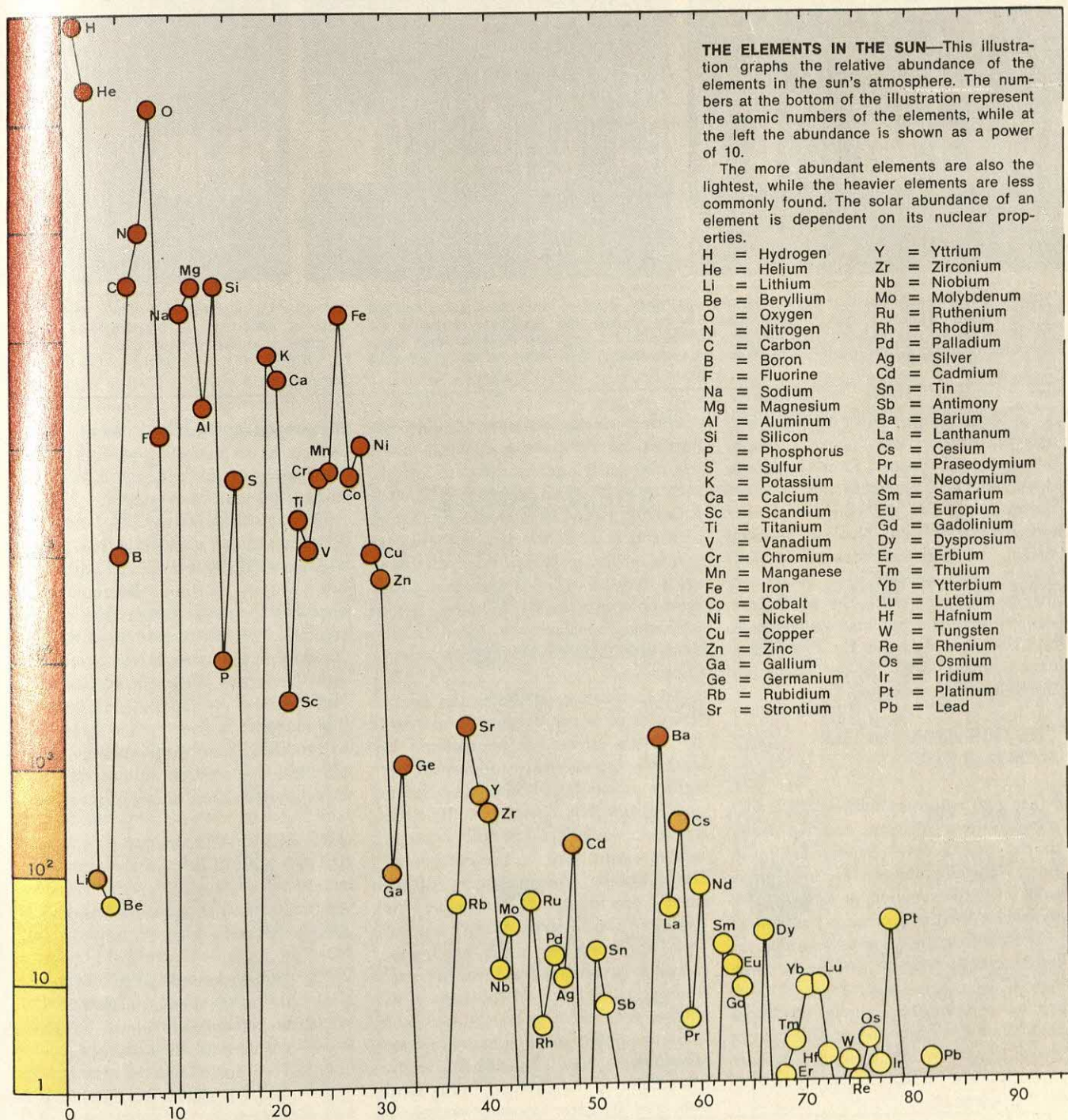
THE LARGEST PLANET—Jupiter is the largest planet of the solar system. Clearly visible in this photograph, taken with the 200-in. Mount

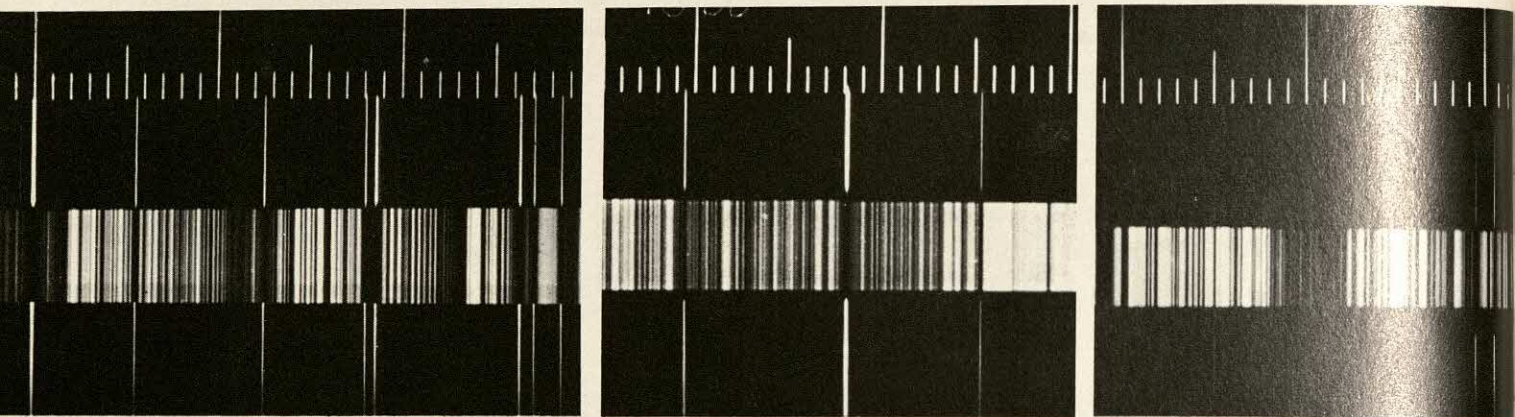
Palomar telescope, are clouds of methane and ammonia—the encircling parallel strips—and the large oval spot of reddish hue. Jupiter is

composed principally of hydrogen and helium, which makes its composition similar to that of the sun.

THE ORIGIN OF THE ELEMENTS

hydrogen—the foundation of the universe





SOLAR SPECTRA—Analysis of these spectra of solar light reveals, among other things, the presence of free radicals of cyanogen, CN (left), methylidyne, CH (center), and imido,

NH (right). Each of these lines, superimposed on the normal color spectrum, is due to the presence of a particular element. Such spectra, therefore, allow study of the condition of

the solar atmosphere. In addition, the brightness of each line is proportionate to the quantity of atoms or molecules.

In its earliest history—over 6 billion years ago—the universe was composed of just one element: hydrogen. From the billions upon billions of atoms in this universal birthstone, all of the elements known today were created. Nuclear reactions within the stars—reactions of fantastic magnitude—fused hydrogen nuclei into the materials of which the Earth, sun, solar system, and universe are made. In fact, hydrogen remains the most abundant element, both on the Earth and throughout the universe.

THE CREATION OF THE HEAVY ELEMENTS

When two hydrogen nuclei collide in a thermonuclear reaction, such as occurs in the sun, a new element—helium—is born. Naturally, nuclear reactions do not stop with the creation of helium from hydrogen, for the process is continuous. It is, therefore, logical to assume that the helium nuclei will, themselves, be bombarded by other nuclei. Some of these nuclear collisions occur under conditions that allow the formation of still heavier nuclei. Thus, in this continual process, elements heavier than hydrogen and helium are formed.

However, the reactions causing the creation of the heavier elements occur less frequently, and for different reasons, than those in which helium is generated. Primarily, given the internal temperature of a star such as the sun, the speed at which nuclear collisions take place is so great that the hydrogen-to-helium fusion reaction occurs readily. In heavy element formation, however, the speed is relatively less, thus reducing formation probabilities.

Another factor explaining the relative slowness of heavy element formation is the simple matter of “population.” Because any given element is formed from lighter elements, it cannot be formed until a sufficient quantity of the lighter elements exists. For example, numerous helium atoms must be present before a single lithium atom can form. Lithium must come into being before beryllium can exist, and so forth. As with any rule, there are exceptions to this one because not all atoms share equal formation probabilities as the result of collisions. Nonetheless, the rule is generally applicable.

At this point, an important conclusion should have been reached: the relative abundance of the elements in the Earth, sun, and universe depends entirely on

the properties of each element’s nucleus and not on its chemical properties. Thus, the history of the universe is in reality nuclear history.

Only after the matter that formed the Earth has cooled sufficiently from plasma to gas, and finally to solid and liquid, was this planet’s history determined by chemical properties rather than nuclear reaction. To understand how a rock became solid, for example, its components must be known. Then the fusion points and chemical attractions of the primordial elements in their molten states must be studied. These properties reveal the chemical composition of the rock and explain the size and shape of its crystals.

THE REVELATIONS OF SOLAR MATTER

An examination of the sun’s composition reveals that:

1. Hydrogen and helium are by far the most common elements.
2. Some elements found on Earth are nonexistent in the sun.
3. The abundance of heavy elements is similar on Earth and in the sun.

Hydrogen and helium have been detected throughout the known universe, while certain elements are apparently absent in the stars.

THE FIRST MOLECULES IN THE SUN

Of extreme interest in solar study is that many elements found in the sun's matter are combined with one another as molecules. The following groups have been discovered in solar spectra:

Cyanogen	CN
Methyldiyne	CH
Hydroxyl	OH

To call these groups true "molecules" is not totally correct because a molecule is a stable union of atoms. In order to form stable unions, these groups must unite with still other atoms. For example, a hydroxyl group (OH) needs one more atom of hydrogen to form a stable water molecule (H_2O). It is more precise, therefore, to call such groups "pieces of molecules," or, in the correct nomenclature, "free radicals."

Why are radicals present in the sun and not molecules? At the elevated temperatures found in and on the sun, atoms, radicals, and molecules that might exist are in a constant state of extreme agitation. If, for the smallest fraction of a second, hydrogen and oxygen were to unite to form a water molecule, that molecule would be immediately bombarded and split by other atoms of solar matter. However, should such a collision occur on the sun's surface, the molecule would not split into its three component atoms. Rather, only one of the hydrogen atoms would be split off, allowing the remaining hydrogen and oxygen atom to form a strong mutual bond. Therefore, if water molecules form, they are instantly shattered. But the hydroxyl radical remains, and in fact is formed in sufficient quantities to be observed with a spectroscope.

In some cases not even radicals can

exist where the surface of a star is considerably hotter than the sun's surface. On such stars, the extreme temperatures cause such violent collisions that even stable radicals (by solar standards) are reduced to their constituent atoms. Within the sun and other stars, however, the process does not stop here. Interior temperatures measured in the millions of degrees cause even the nuclei of atoms to disintegrate into subatomic particles.

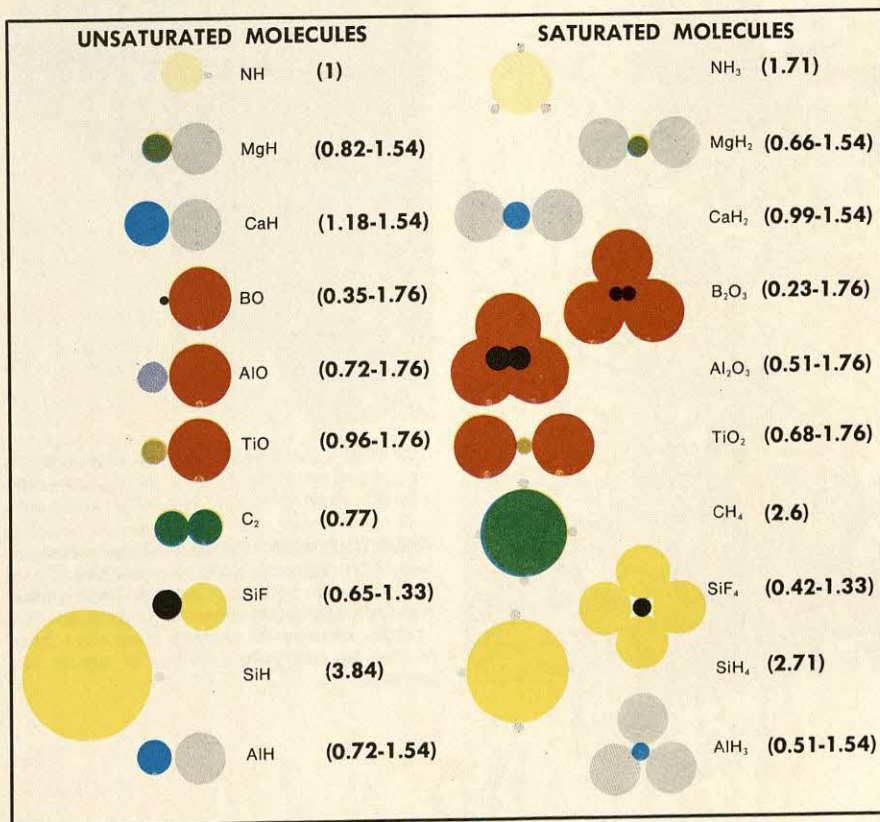
At decreased temperatures, both radicals and molecules can exist as stable entities, and both are similar to those found on Earth. At lower temperatures, the atom re-forms its nucleus and electron structure, although the temperatures fall between 10^4 and 10^6 degrees.

Below $10,000^\circ K$, then, radicals and molecules begin to form, and at about $2,000^\circ K$ most matter acquires molecular form. Thus, if a part of the sun were to

fly into space, and were unable to sustain a nuclear reaction, it would gradually cool until it became a solid mass of matter.

All atoms having reciprocal chemical attraction will combine, forming all possible molecular combinations. The extent of such combination depends on the degree of attraction between atoms or their abundance in the original stellar matter. Only the most elemental bits of matter can exist at the temperatures encountered near the center of the sun—about $20,000,000^\circ K$.

TWO TYPES OF MOLECULES—Unsaturated molecules do not have tight links between their constituent atoms, and are called free radicals. These are found in the sun. Saturated molecules, however, are tightly joined groups of atoms. They are true molecules such as those found on Earth. The scale used here is $1 \text{ A} = 2.5 \text{ mm}$ (one A is equivalent to 10^{-8} cm).



LIFE INVADES THE EARTH

The Earth is populated today by living things of almost every imaginable sort. Vegetation grows on nearly all land above sea level, on the seabeds of the continental shelves, and floating in the sea itself. Animals, too, range over the Earth and in the sea, and some of them fly in the air. Winds carry seeds, pollen, spores, and microscopic bacteria, fungi, and algae.

The capacity of living beings for reproduction is truly remarkable. Any species quickly populates any hospitable environment that is open to it. The sheer mass of living matter in the world is tremendous. But it was not always so. There was a time when there was no life on Earth. The air, the land, and the

sea were sterile, and the composition of the air and the natural waters were probably much different from what they are now.

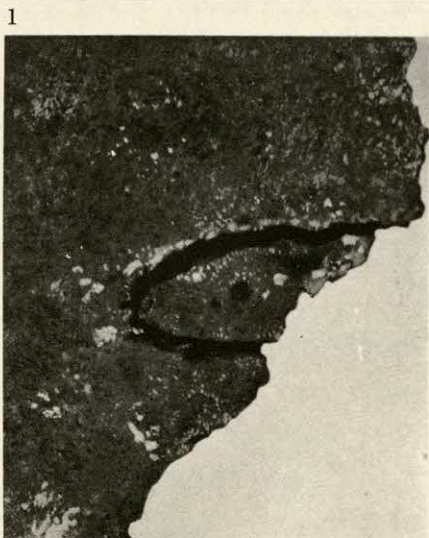
Today the Earth's atmosphere contains two gases directly or indirectly essential for nearly all forms of life: oxygen and carbon dioxide. These gases are also dissolved in the oceans. With the exception of the pollution produced by man's industrial activities, air contains practically no organic matter, and the organic compounds in rivers, lakes, and oceans are those resulting from the incomplete decomposition of living things.

Organisms are composed largely of water and organic compounds. By the process of photosynthesis, green plants

convert two inorganic compounds, carbon dioxide and water, into the organic compounds of which their bodies and the bodies of the animals that eat them are composed. For this reason it was once assumed that green, photosynthetic plants must have been the first organisms to appear on the Earth. But such plants are complex and could only have come from simpler ancestors. Yet, if simple, nonphotosynthetic organisms were the first living beings, what was the source of the organic compounds of which they were composed?

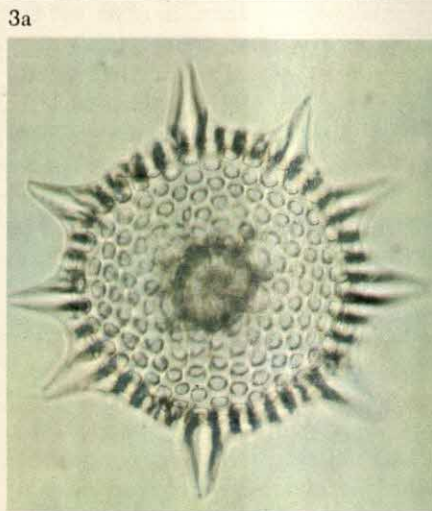
ORIGIN OF LIFE

Recent theories hold that the primitive

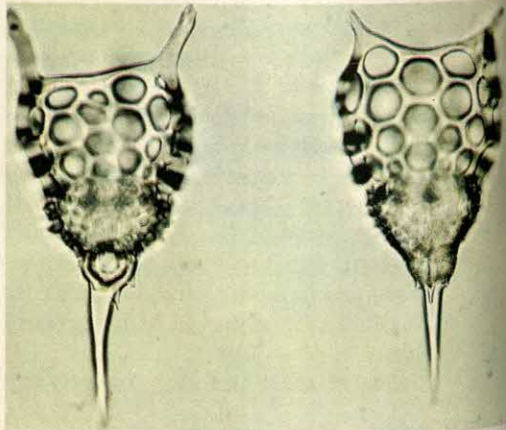


CORYCIUM ENIGMATICUM—This fossil, which was found in Finland, may be a blue-green alga that lived more than one billion years ago.

CRENOTHRIX POLISPORA—These filamentous iron bacteria (left) are enclosed in a sheath that sometimes is strongly impregnated with iron hydroxide. Deposits of iron ore that contain remains of bacteria may have been formed by metabolic activities of similar iron bacteria.



3b



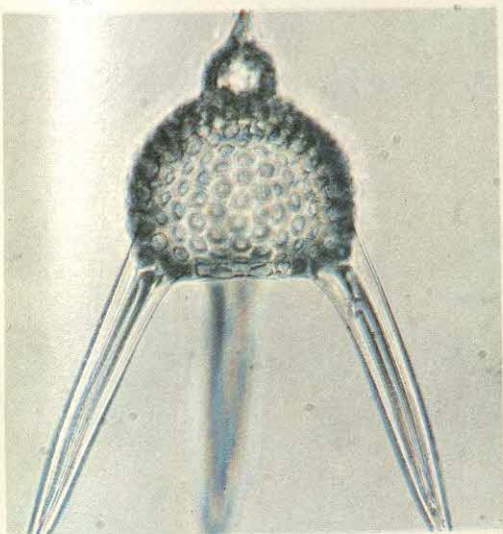
atmosphere and oceans of the Earth contained large quantities of ammonia, methane, and hydrogen, compounds that, if present in great quantities today, would kill most living things. Laboratory research has shown that these compounds and water could have formed organic compounds if a suitable energy source were available. Natural energy sources that would have been available were ultraviolet radiation from the sun, heat from volcanoes, or electrical discharges from lightning. Biochemists believe that simple organic compounds and even some complex ones were formed in this way in the sterile waters of the oceans without the need for the intervention of the metabolic activities of living things.

The compounds produced in this way are believed then to have become organized into simple structures that resembled living cells in some ways but not in all and therefore were not alive. Probably many different varieties of these prebiological systems came into being and disintegrated without leaving any evidence of their existence. Only when some of them acquired all the characteristics that are associated with life did the first living cells appear. Possessing the power of reproduction, they produced more organisms like themselves and began to populate the oceans. The chemical evolution that preceded the appearance of life on earth probably required many millions of years.

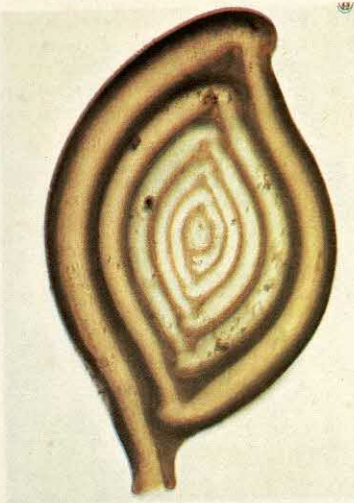
EARLY LIFE ON EARTH

The first living things probably resembled some of the bacteria existing today. Rather than producing their own food by photosynthesis, they absorbed organic compounds from their environment and used them as food. When the supply of these compounds was exhausted, organisms might have died out if photosynthetic organisms had not evolved from the nonphotosynthetic ones. These new organisms probably were algae resembling the blue-green algae of today. The photosynthetic activities of these primitive algae and their descendants ensured the ever-replenished food supply on which all life depends today. By their

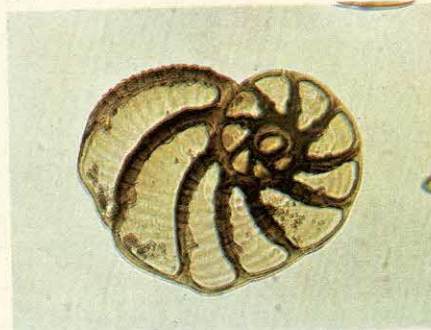
RADIOLARIA—Radiolaria are protozoa (unicellular animals). They are all marine creatures, and their siliceous skeletons do not decay after death. Thick deposits of their skeletons, radiolarian ooze, are found on the floor of the Pacific and Indian oceans. Two examples of radiolaria are shown, *Heliodiscus humboldti* (Illustration 3a) and *Podocystis triacanthos* (Illustration 3b). (about 250 X)



4b



4c



4d



FORAMINIFERA—Most of these protozoa have a calcareous shell, the shape of which varies with the species. Accumulations of the shells of dead foraminifera have formed valuable deposits of chalk and limestone. Illustration 4a shows *Bolivia robusta* (250 X), Illustration 4b, *Spiroloculina limbata* (250 X), Illustration 4c, *Peroplis pertusus* (72 X), and Illustration 4d, *Lychnocamium tripus* (300 X).

metabolic activities living things changed their environment and produced the oxygen and carbon dioxide that life also requires today.

From the first few simple organisms evolution has produced numerous species of plants and animals of various degrees of complexity. Even during the Precambrian era several recognizable species of animals had evolved. Not only were there unicellular protozoa, but some multicellular animals such as the sponges and the relatively complex echinoderms were living by the end of that era.

Some trails and burrows of worms also have been found in Precambrian rocks. Science is striving to fill in the mysterious gap between the Precambrian period, for

which almost no animal fossils have been found, and the Cambrian period, when animal evolution was well advanced. Almost every major animal group in the fossil record was occurring in the Cambrian period (about 550 to 570 million years ago).

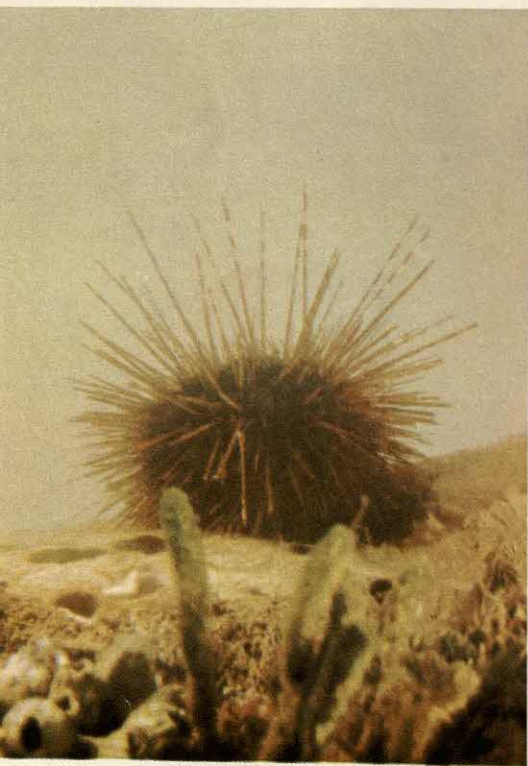
Conjectures about the ancestry of the highly evolved Cambrian animals include these possibilities: they may have been forms with hard skeletons that were destroyed by metamorphosis of the rocks containing them; Precambrian organisms may have been highly evolved but lacking hard parts; or ancestral forms may have been active types in which hard skeletons would be useless. A breakthrough that heartened the scientific com-

munity in 1965 was the discovery of a clamlike brachiopod fossil on Victoria Island, Canada, in strata more than 720 million years old.

Probably the oldest fossil form reported to date comes from South Africa. It is a tiny bacterium-like form, revealed and studied by optical and electron microscopy; and it is about three billion years old—indicating that life began earlier in the Precambrian time than had been thought.

Microfossils are usually collected not singly but by the hundreds or even thousands in rock samples. Not until his samples are carefully processed does the collector know for sure that they contain fossils.

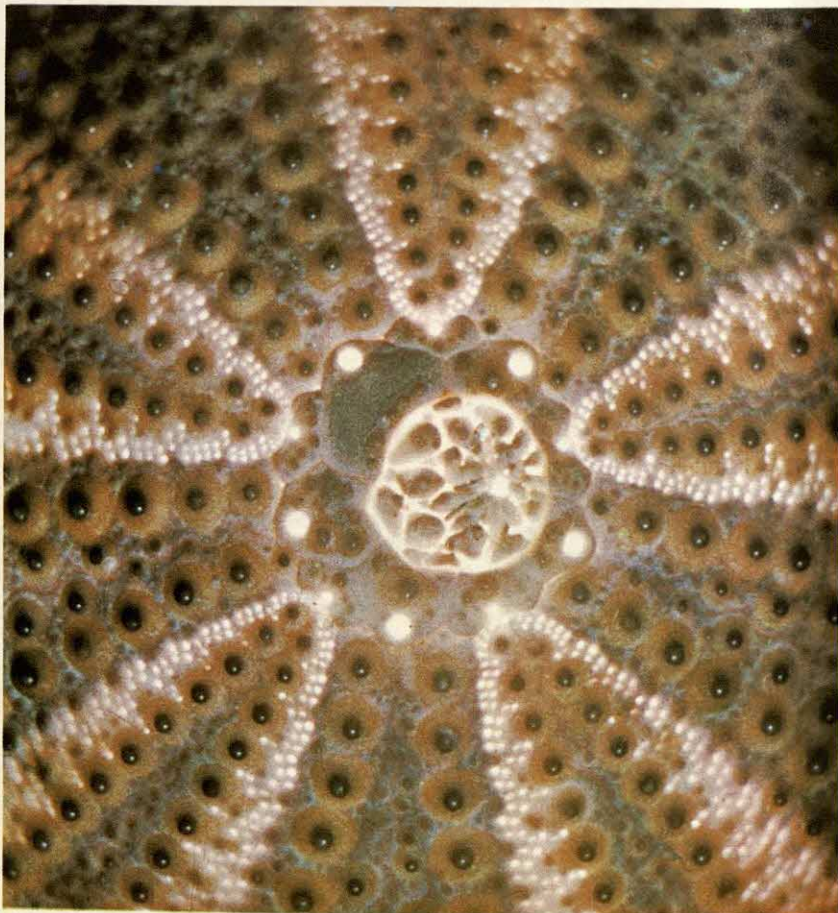
5a



SEA URCHIN—The present-day sea urchin shown in Illustration 5a is descended from relatives that lived about 500 million years ago in the Ordovician period. The abundance of their fossils is due to the fact that their rigid

calcareous skeleton fossilizes easily. Illustration 5b shows the skeleton of a sea urchin with its clearly pentactinal (five-rayed) structure. Also clearly visible are the calcareous plates, which are firmly joined together.

5b





RIVULARIA—This blue-green alga occurs in long, tapering filaments that live free in the water. Fossils believed to be those of blue-green algae have been found in Archeozoic (Early Precambrian) rocks. (640 X)



PART 4

- 85 Other Galaxies
- 89 Inside the Sun
- 94 The Eclipse

ASTRONOMY | an ancient science that has come of age

Surely every person who watched Astronaut Neil Armstrong walk on the moon, or waited up past midnight to see the Mariner television pictures of the Martian surface as they were radioed back from Mars, knows that astronomy is a modern science using the newest technology to probe the nature of the universe beyond our own planet. But astronomy is also one of the oldest of the natural sciences. The Babylonians kept astrological records of the movements of the sun, moon, and planets, and were able to predict their motion rather accurately. Calendar making and timekeeping were the tasks of astronomers long before the telescope was invented. In this introductory volume three articles on astronomy deal both with the historical aspects of astronomy and with modern research requiring the use of large optical and radio telescopes.

"Other Galaxies" describes how it has been possible to determine the distances to other systems of stars similar to our own galaxy, the Milky Way. This has not been an easy matter because the distances of other galaxies are so vast that conventional methods of distance determination (such as triangulation) are useless. The methods require the use of large telescopes, such as the 200-in. Hale telescope on Mount Palomar, to photograph variable stars in these galaxies and to analyze spectroscopically the light of these galaxies to determine their speed of recession.

"The Eclipse," on the other hand, describes work that was begun 3,000 years ago by the Chaldeans, who kept careful records of eclipses—work that has been continued to this day. The awe-inspiring spectacle of a total solar eclipse must have motivated early civilizations to study the phenomenon, for the Chaldeans were able to predict the occurrence of most eclipses. Nowadays, though a total solar eclipse is no less spectacular, astronomers travel thousands of miles just to study the unique effects that accompany these spectacular events.

"Inside the Sun" tells of some of the work done by modern theoretical astronomers. One of the most successful theoretical astronomers was Johannes Kepler, who used Tycho Brahe's observations of the movements of the planets to discover the laws that govern the motion of these bodies. Kepler's tools were pen and paper; the tool of the modern theoretical astronomer is likely to be a huge electronic computer that can perform all of Kepler's computations in a matter of seconds. These machines are needed to make the tremendous number of calculations required to produce a mathematical model of the interior structure of a star. Even though the observational data is scant (for most stars, astronomers observe only the degree by which the intensity of light varies with wavelength or color), it is possible to compute how the temperature, pressure, and chemical composition vary from the center of a star to its surface. Furthermore, it is now possible to describe in some detail how the internal structure changes with time for a given star; that is, the evolution of a star can be predicted.

Finally, several areas of astronomy have made impressive gains in the last decade. Planetary astronomy, stimulated by the space effort, is at the doorstep of gaining firsthand information about other planets in the solar system. After hundreds of years of speculation, astronomers will learn just how accurate their ideas about these planets have been. Unmanned probes to Venus and Mars have already confirmed suspicions of the high surface temperatures on Venus and surprised almost everyone with the pictures of a crater-scarred Martian surface. In addition, the discovery of new kinds of astronomical objects—such as pulsars, quasars, and "x-rays stars"—has provided intriguing new puzzles for astronomers. These new phenomena are still poorly understood, but their properties and current interpretations, as well as the latest in planetary results, are covered in Volumes 8 and 9.



OTHER GALAXIES

star systems receding
toward the infinite

1



THE SOMBRERO—This galaxy, known as Sombrero for its resemblance to a Mexican hat, contains innumerable stars spread out in the form of an ellipse. A large quantity of

matter in the form of fine dust is scattered between the stars along a plane that intersects the equator of this galaxy, preventing observation of the stars behind the dust. Similar dust

is also found along the equatorial plane of the Earth's Galaxy, obscuring many stars and galaxies behind it.

Looking at the mass of stars visible on a clear night, it is difficult to believe that only four galaxies, or extragalactic nebulas, can be seen outside our own Galaxy, the Milky Way. Billions of others exist, however, at distances enormously greater than the naked eye can see. Two of the

galaxies that can be seen beyond ours are spiral nebulas in the constellations of Andromeda and Triangulum. The other two are the Magellanic Clouds, a pair of large nebulas far from the Milky Way and visible from the Southern Hemisphere. These two extragalactic nebulas

mark the limit of distance that man can see with the unaided eye, a distance of some 2 million light-years.

The extragalactic space where these and other galaxies exist in unlimited numbers has been called the realm of nebulas. This article discusses the geog-



SPIRAL NEBULA—The spiral form is common among extragalactic nebulas. The exact origin of the spiral arms is uncertain, but they are undoubtedly related to the fact that the inside part of the nebula rotates faster than the outside.

lines he can then calculate the distance of the object from him. In the same way, if an observer waits six months for the Earth to move from one point in its orbit to a point opposite, the nearer stars will seem to have moved slightly. If this apparent displacement, or parallax, is measured, the distance of the object from the Earth can be calculated. This parallax technique is of no use, however, in measuring the enormous distances between the galaxies. Other methods must be used.

A photograph of a nearby galaxy taken with a powerful telescope reveals many of the brighter stars that make up the galaxy. The stars are not equally bright; if a great number of them were placed at the same distance from the Earth, the difference in their intensities would be obvious. The brightest ones would give as much as 100 million times more light than the dimmest ones. There are bright and dim stars in any galaxy, but the dimmest ones, even in the nearest galaxies, cannot be observed with any telescope. The very bright stars in some of the most distant visible galaxies, however, can be seen.

The brighter stars can be photographed and their luminosity can be measured from the amount of light that is recorded on the photographic plate. Comparative measurements taken over a period of time reveal that the luminosity of some stars changes. These are the variable stars—stars whose light fluctuates. The light of the brightest stars fluctuates over a longer period of time than that of the dimmest stars. It is necessary only to identify the way in which some of these stars fluctuate and then measure the period of their variations to determine their intrinsic brightness, or luminosity power. Their distance can also be calculated, because their degree of brightness depends partly on their distance in a way similar to a light in a valley that is observed from the top of a mountain—its distance can be calculated, provided its intrinsic brightness is known.

raphy, and some of the physical laws that apply to extragalactic nebulas, which are complete stellar systems, or galaxies.

MEASURING THE DISTANCE OF NEARBY GALAXIES

In measuring the relatively small distances between the bodies of our own solar system or between the sun and the

nearer stars, the same method of triangulation can be applied that is used to measure distances on the Earth. Imagine a line drawn from an observer's eyes to a distant object and another line extended from that object to the horizon. If the observer changes his position slightly and repeats the operation, the second line appears to touch the horizon at a different point. With these three

GALAXIES RECEDING TOWARD THE INFINITE

When a galaxy is close enough for its brighter stars to be seen distinctly, it is bright enough for a spectral analysis of its light to be made. The spectroscope shows that galaxies are made up of stars that are, on the average, similar to our sun, but not as much information is available from their spectra as from the spectra of nearer stars, such as those in our own galaxy. But one phenomenon that can be observed is of great importance to the understanding of stars that are far beyond the range of instruments. The two most marked spectral lines of extragalactic nebulas (the lines at the violet end of the spectrum) shift toward red as the nebula's distance from the Earth increases. When any spectral line appears to shift from its normal position, the light source emitting it is moving in relation to the Earth. If the line has shifted toward the red end of the spectrum, the light source is moving away; if it has shifted toward the violet end, the source is moving closer. Because the two lines in their spectra are constantly shifting toward red, all galaxies are moving away from the Earth. Illustration 3 shows how this shift of spectral lines increases in proportion to the distance between a galaxy and the Earth.

A diagram can be made showing that the speed of recession of the galaxies is proportional to their distance. This relationship between the distance of the galaxies and their spectral shift has proved so constant that it is used by astronomers to calculate the distance of those galaxies whose stars cannot be distinguished separately—galaxies up to several hundred millions of light-years distant from the Earth.

Imagine that an observer is stationed at the corner of the grid shown in Illustration 5a, every square of which contains a galaxy. If in time this grid expands, all the galaxies in their squares will move away from him at a rate proportional to their distance (Illustration 5b). The Earth is in the same position as the observer; the galaxies are moving away from the Earth with a velocity proportional to their distance.

POSITION OF EXTRAGALACTIC NEBULA CLUSTER

DISTANCE IN LIGHT-YEARS



VIRGO

22,500,000



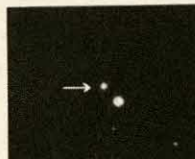
URSA MAJOR

300,000,000



CORONA BOREALIS

400,000,000



BOOTES

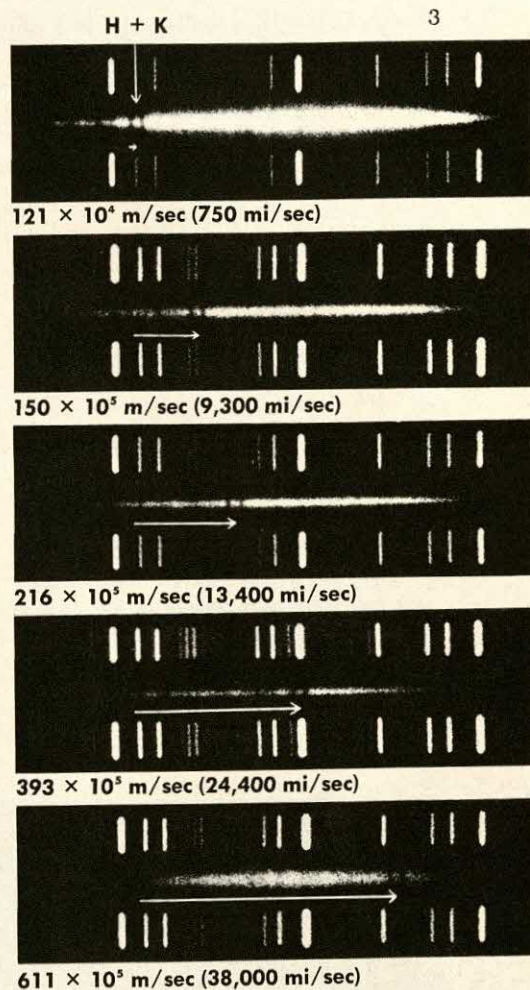
700,000,000



HYDRA

1,100,000,000

MEASURING THE DISTANCE OF THE GALAXIES—The spectrum shows that the two most marked lines of a nebula (lines H and K, which indicate calcium), shift more and more toward red as the distance between the



Earth and a nebula increases. The nebulas are at ever-increasing distances from the Earth. The greater their distances, the more the H and K lines appear displaced toward red (white arrows).

EXPANSION OF THE UNIVERSE

All the matter in the universe is gradually spreading out into ever-expanding space. Physicists do not yet know for sure, however, if the shift toward red of the light from distant galaxies (or the lengthening of radio waves they emit, which is basically the same phenomenon) is due to some unknown phenomenon that could simulate a recession of the galaxies. The light emitted by these galaxies has taken hundreds of millions, or even billions, of years to cross space, and no one really knows what happens to light when it travels so far.

It is important to point out, however, that if the time when all the galaxies should have been close together is estimated, the result is a date a little before that commonly accepted for the formation of the solar system. The estimate is, however, still very uncertain, as are all assumptions about the origin of the solar system.

DISTRIBUTION OF GALAXIES IN SPACE

The galaxies are fairly evenly distributed in space. However, if an observation is made toward the equatorial plane of the

Earth's Galaxy, the Milky Way, few galaxies will be seen. The observer must look through clouds of fine, light-absorbing interstellar dust that are thicker on this plane than elsewhere in the Milky Way.

"COLLIDING" GALAXIES

In some photographs of galaxies a pair appears so close together that they seem to have collided and merged. Although two galaxies may appear superimposed on each other, they are usually at different distances along the same line of vision.

Despite the fact that galaxies contain billions of stars, if two galaxies collided only two stars, at the most, would actually collide because the average distance between stars in a galaxy is ten million times the diameter of one of them. With this amount of empty space between the stars, collision is not likely.

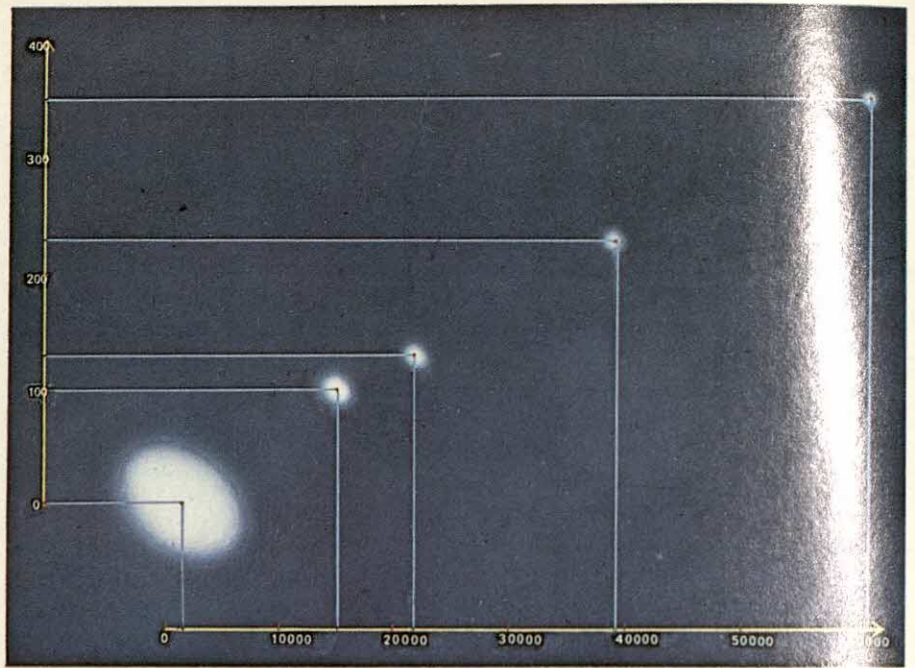


DIAGRAM OF THE VELOCITY OF RECESION—The speed of recession of the galaxies is directly proportional to their distance from the Earth's Galaxy; that is, the more distant

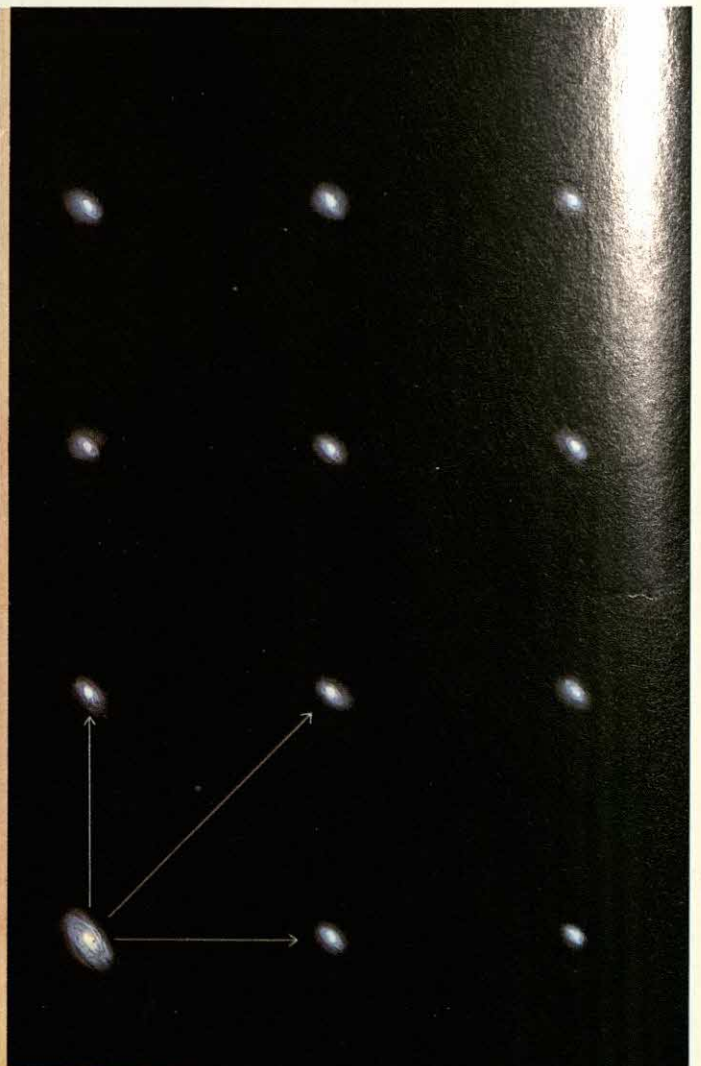
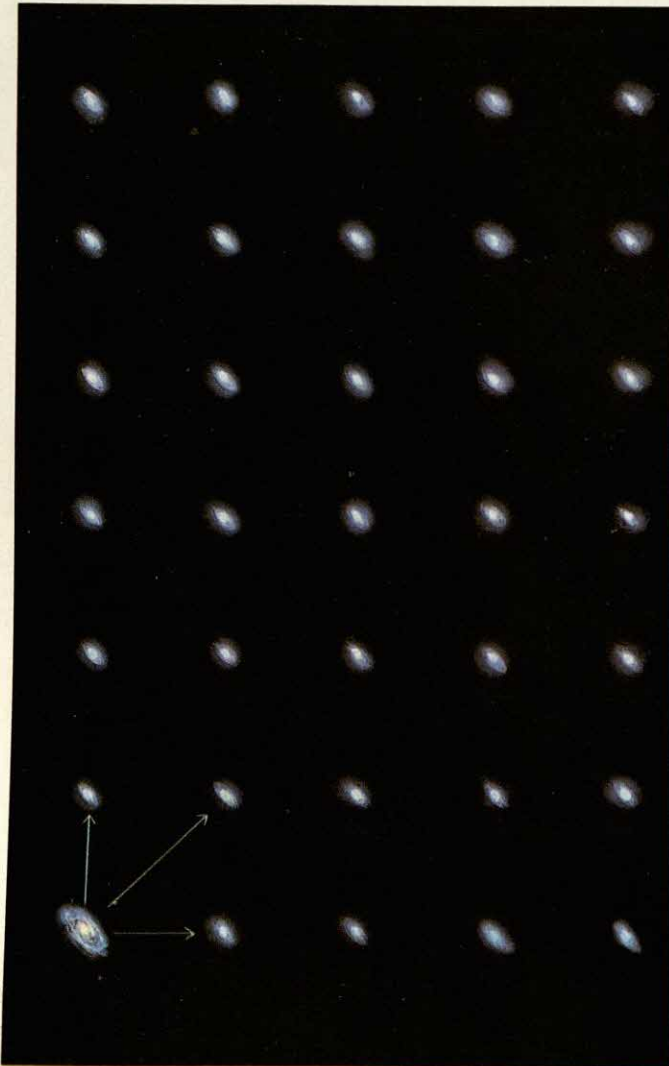
the galaxy, the faster the nebula recedes. At the side is the distance in millions of light-years and at the bottom is the speed of recession in miles per second.

THE UNIVERSE EXPANDS—Illustration 5a shows an imaginary grid, the points of which are made up of galaxies. If the grid expands

in the course of time (Illustration 5b) then from any one galaxy other galaxies recede at a speed proportional to their distance.

5a

5b



INSIDE THE SUN | a nuclear furnace for the solar system

Since man first raised his eyes above the Earth on which he walked, he has been dazzled by the star that is the Earth's sun. Although the sun appears to be the largest and brightest of all the stars, it is only an average star among the billions in the universe. Nonetheless, it remains a source of enormous energy that sustains life on Earth.

Scientists who have attempted to measure this flow of solar energy have encountered great difficulties, in particular those caused by the screening effect of the Earth's atmosphere. The higher layers of the atmosphere—those 30 to 60 miles above the Earth—absorb some of the ultraviolet radiation of the sun. Lower layers, because of their humidity and carbon dioxide content, absorb much solar radiation of infrared, visible, and ultraviolet wavelengths. Even the oxygen and nitrogen in the atmosphere contribute some absorption and increase the difficulty of measuring solar energy.

Because the instruments necessary for measurements of solar energy are not easily transportable by balloons, rockets, or artificial satellites, scientists have tried to minimize the screening effect by carrying out experiments from atop mountains in the driest possible climate. These locations provide the least possible interference from humidity, fine dust, and atmospheric density.

MEASUREMENT OF THE SOLAR CONSTANT

To measure the energy that the Earth receives from the sun, scientists use two identical calorimeters. One calorimeter is exposed to solar radiation; the other, placed close to the first, is shielded from the radiation. The exposed calorimeter, covered with a black paint that transforms all radiations—from infrared to ultraviolet—into heat, becomes heated, while the shielded calorimeter remains

cool. The difference in temperature between the two instruments is the amount of energy received by the exposed calorimeter.

This measurement can be carried out regardless of whether the sun is high or low above the horizon. When the sun is low, its rays travel through a greater thickness of atmosphere and thereby undergo greater absorption. From the difference in the quantity of energy received in the two cases (high sun and low sun), scientists can calculate the amount of radiation per second falling on a square centimeter of surface in the outermost layer of the atmosphere—an amount called the solar constant. (Designating this amount a **constant** assumes that it does not vary according to time and weather; actually, negligibly small variations occur.)

A flow of energy of 1,370,000 ergs per square centimeter per second reaches the Earth perpendicular to the direction of the rays of the sun. (An erg, a unit of energy or work, equals the work done by one dyne acting through a distance of 1 cm. A dyne equals a force under whose influence a particle with a mass of 1 g would experience an acceleration of 1 cm/s during each second.) In terms of thermal units, 1,370,000 ergs is equal to slightly less than 2 calories/cm² per minute. In mechanical units, the entire surface of the Earth receives 47,000,000,000 kilowatt-hours per second.

However great this quantity of energy may seem, it is only 1 two-billionth of all energy emitted by the sun. The Earth is a relatively small body about 93,000,000 miles from the sun—a mere speck in the vast expanse of space through which solar radiation is dispersed.

RADIATION OF THE SUN'S SURFACE

Because the space separating Earth and sun is largely a void, the amount of energy that leaves the surface of the sun can be calculated from the flow of energy (the quantity of energy per unit of area) that reaches the surface of the Earth. Such calculations show that each second

THE HEAT OF THE SUN—The enormous quantity of solar energy that reaches the Earth is an infinitesimal part of the total amount

produced by the sun. The amount of solar energy reaching the Earth in one day would melt a layer of ice about 56 ft thick.



a square centimeter of the solar surface emits 6.32×10^{10} ergs of energy.

A force of about 70,000 horsepower is needed to maintain the flow of energy that crosses a square yard of the photosphere (the surface of the sun) to be radiated into space. If the sun were covered with a layer of ice, the heat radiated would melt it at a rate of 12 m (about 40 ft) in depth each second. If all the energy radiated were transformed into mechanical energy, the force would be great enough to push the Earth so far from the sun that in six months the planet would no longer be subject to significant gravitational attraction. The Earth would be propelled through space at an initial velocity of about 10 km per second (about 6 mi per second).

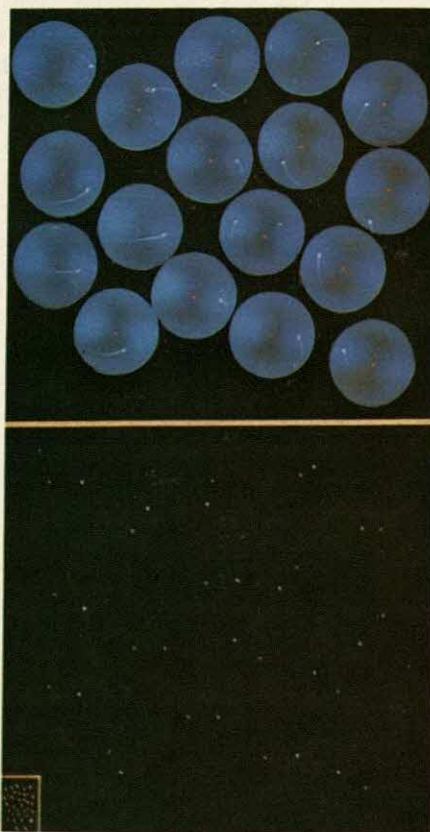
To understand how the sun maintains this tremendous flow of energy requires an understanding of its internal structure. Because scientists cannot see below the surface of the sun, knowledge of its interior is based on calculation. The scientists gather together all that is known about the sun from observations: its mass, size, composition, and the amount of energy it radiates. By considering these quantities in the light of known physical properties of matter, the nature of the solar interior has been determined.

THE SOURCE OF ENERGY

For a great many centuries the source of the sun's vast energy remained unknown. Early in the present century astrophysicists concluded that solar energy stems from nuclear reactions deep within the sun.

The sun is made up primarily of hydrogen. The only other element present in sizable amounts is helium. Other elements, while of great importance to the appearance of the sun, are far less abundant by comparison with hydrogen. Deep within the sun the pressure and temperature are extremely high; at its center the pressure reaches trillions of atmospheres

2a



b

IONIZED GAS—The hydrogen atoms in Illustration 2a are compressed, occupying no less than a certain volume. If the gas is ionized, its atomic structure is broken; then, separated electrons and protons occupy a much smaller volume than their corresponding atoms and are consequently more compressed. Illustration 2b shows free electrons and protons that, when compressed, occupy the volume represented by the lower rectangle.

while the temperature rises to tens of millions of degrees. Under these conditions the atoms become completely ionized and are stripped of their electrons, causing the nuclei and electrons to act as a gas at very high density. In this regime of high pressure, temperature, and density, nuclear reactions take place, releasing enormous amounts of energy.

A helium nucleus consists of two protons and two neutrons, and weighs almost four times as much as the single

proton which forms the hydrogen nucleus. The "almost" is extremely significant. According to Einstein's famous equation, $E = mc^2$, the destruction of a mass, m results in an energy release equal to that mass times the square of the speed of light, c . The constant c is a very large number, and a small difference in mass can mean a very large amount of energy. If four hydrogen nuclei can be made to combine into one helium nucleus, the mass loss releases an enormous amount of energy. One gram of hydrogen converted into helium will release 6.4 billion-trillion ergs of energy. This is about 2 million kilowatt-hours of energy from a mass of about 0.035 ounces. The vast energy released by the sun requires the conversion of 600 million tons of hydrogen into helium each second. Even though the sun is a middle-sized star, it is large enough to shine at this rate of conversion for more than 10 billion years.

NUCLEAR REACTIONS IN THE SUN

The hydrogen in stars is converted to helium through two series of nuclear reactions. In the first, known as the proton-proton cycle, two hydrogen nuclei combine to form a type of heavy hydrogen known as deuterium. The deuterium combines with another hydrogen nucleus to form a kind of light helium. Although this light helium does not react with another hydrogen nucleus, two of these light helium nuclei eventually combine to form normal helium and release two hydrogen nuclei. The net process is the conversion of four hydrogen nuclei into a single helium nucleus.

The second series of reactions is more complicated. In this series—the carbon-nitrogen-oxygen cycle, or C-N-O cycle—heavier elements act as catalysts. Hydrogen initially combines with carbon and in a complicated series of reactions various forms of carbon, nitrogen, and oxygen are formed through combination

with hydrogen and through nuclear disintegration. When the cycle is complete, all the heavy elements are back in their original state, and the end result is again the combination of four hydrogen nuclei into a single helium nucleus, accompanied by a great release of energy. Most of the sun's energy comes from the proton-proton cycle. The C-N-O process is important in heavier stars having a higher central temperature.

The behavior of temperature, pressure, and density inside the sun is shown in

Illustration 3. This information stems from straightforward calculations based on four laws of physics that determine the structure of the sun and every other star. The first is the law of hydrostatic equilibrium, which states that the amount of outward pressure at any point within the sun must balance the weight of all the matter above that point. In spite of the high temperatures, pressures, and densities within the sun, solar matter still acts as an ideal gas. The pressures involved are those caused by the collisions of the particles that make up that

gas. In some parts of larger stars, where densities are much lower, the radiation pressure of light may also be important; but in the sun, the pressure that holds up each layer is the gas pressure at that level. In combination with the other physical laws, this law allows calculation of the internal pressures and densities in the sun.

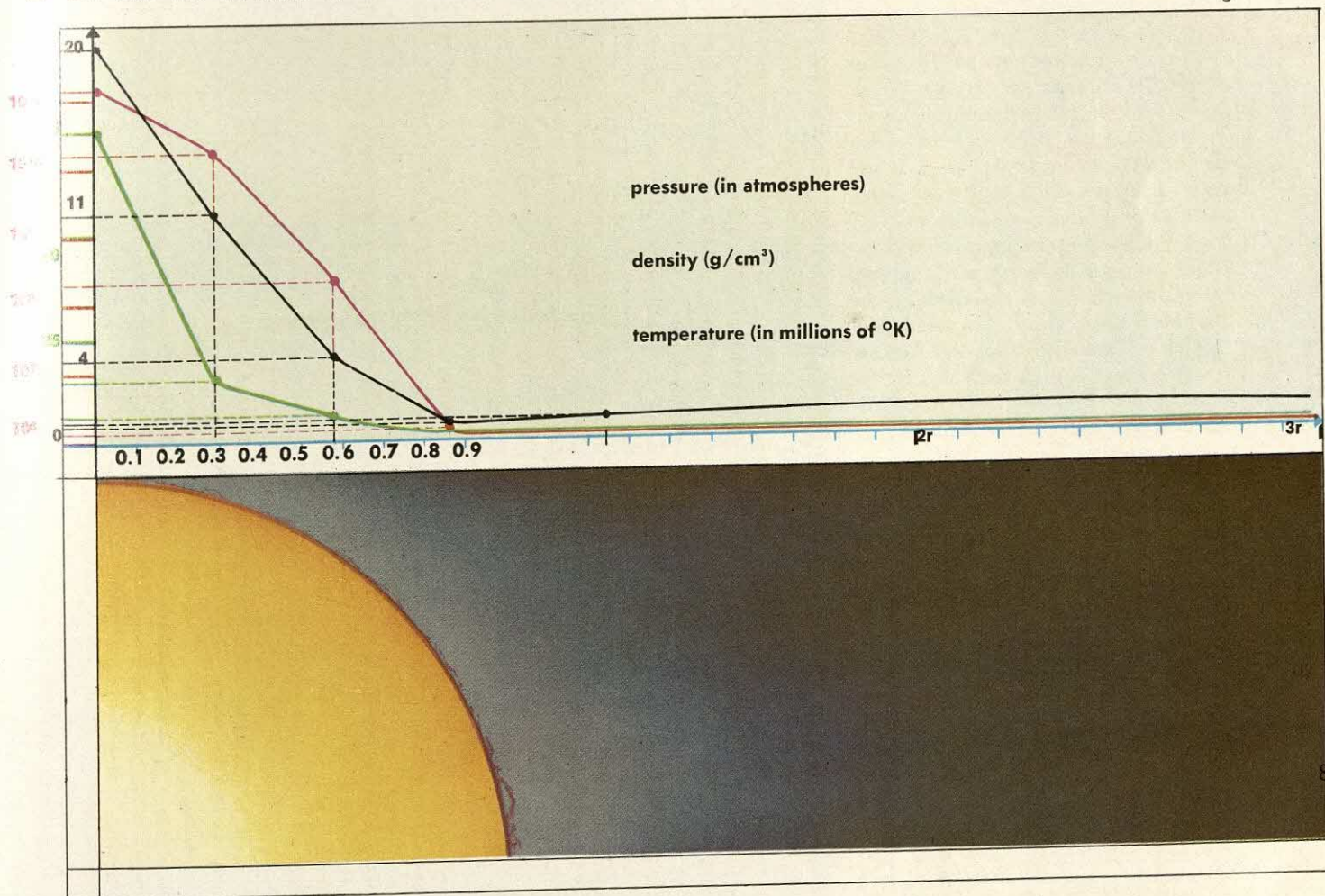
The second law is that of thermal equilibrium. Simply stated, the law maintains that there is no place in the sun for

TEMPERATURE, PRESSURE, AND DENSITY OF THE SUN—The illustration shows the

changes in temperature, pressure, and density of the sun according to the distance from its

center. These data were obtained by calculation, but indirect observations confirm them.

3



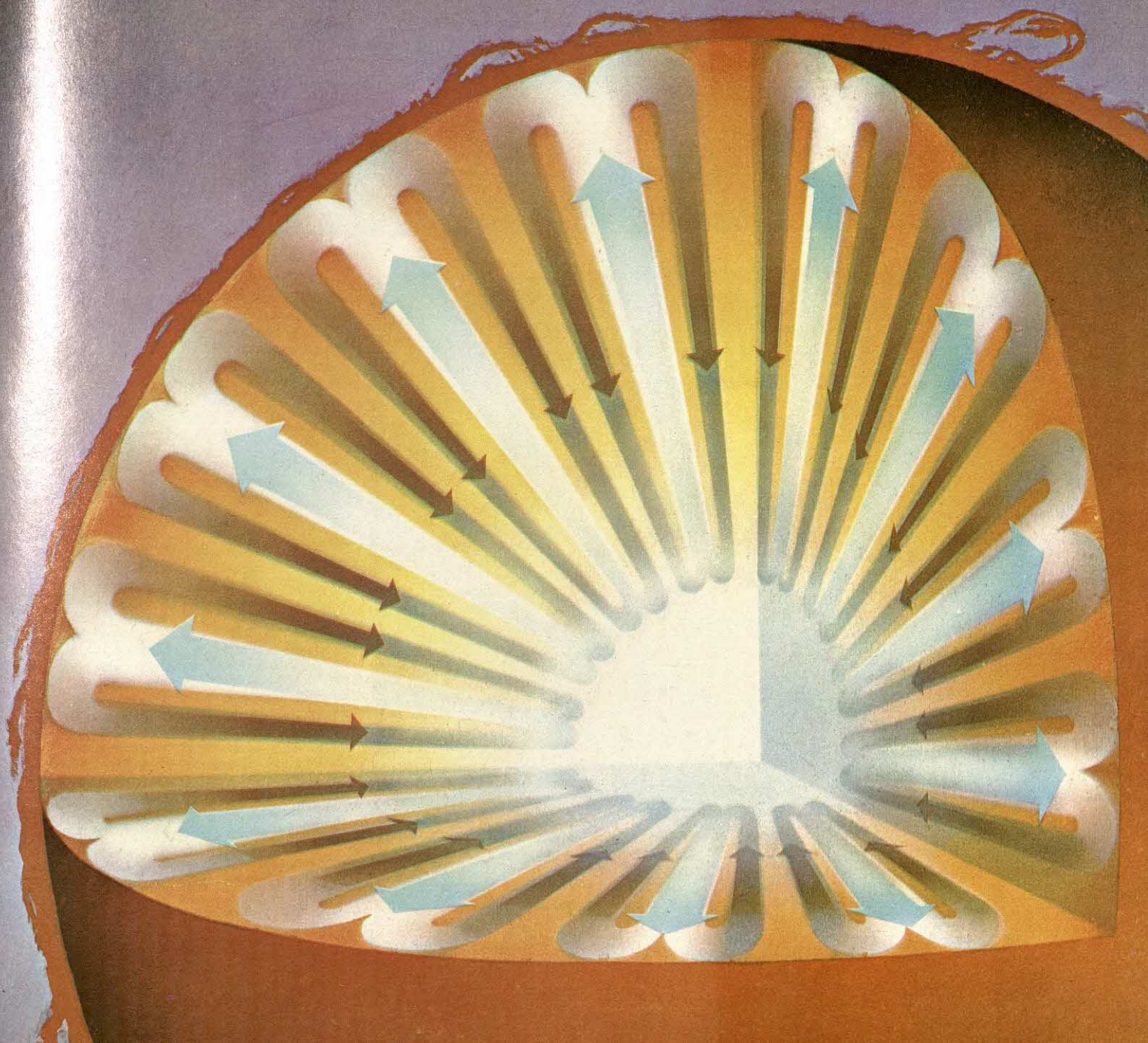
heat to be stored for a great length of time. Once the sun had settled down to a stable condition—as it did millions of year ago—the energy released by nuclear processes in the center of the sun must find its way through each level of the sun until it is finally released at the solar surface. The energy may change form as it passes through the sun. At the center most of the energy is in the form of very high energy x-rays. As the energy passes through the sun, it interacts with the material in the sun and changes its frequency distribution until at the surface most of the energy is in the visible region of the spectrum.

The third law is an equation of state. This equation reveals how temperature, pressure, and density are related. As stated above, the material in the sun acts as a normal gas. Because of this its equation of state is the well-known perfect gas law, which forms an essential part of the model of the solar interior.

Finally, a description of the interior of the sun must take into account how the energy released at its center is transported through the various layers. Energy can be transported through conduction, radiation, and convection. Conduction is not an important process in the gases of the sun. All energy transport is by radiation and convection. As the vast amount of energy released by nuclear reactions deep inside the sun works its way through the sun, it is absorbed by the particles it strikes and is then reradiated. This process of absorption and reradiation of energy changes the x-rays of the sun's interior to visible light at its surface. In some regions of the sun energy is transported by convection. If the distribution of temperature and density is favorable, a large quantity of hot matter moves upward to a cooler layer where it loses its heat and falls back toward the hotter regions. In this manner, a flow of solar matter is set up, moving heat from lower layers to higher layers. By comparison with radiation, convection is an extremely efficient means of heat transfer; however, it requires a very limited range of temperature and density distribution if it is to occur. The bulk of the energy transport in the sun is by radiation. In certain limited regions it is probable that convection zones exist and that in these regions convection is very important.

Thus, with these four physical laws, and with our present knowledge of the size, mass, composition, and energy of the sun, scientists can describe its interior with confidence, even though only its surface is visible.

CONVECTION CURRENTS—This illustration of the sun in section helps explain the emission of energy through convection and radiation. The plasma in the interior, heated by thermonuclear reactions, becomes less dense and rises to the surface. There the plasma releases its energy, which is radiated into space. As the plasma cools, it returns to the center of the sun to repeat the cycle. This convective movement of plasma is similar to that of water boiling within a saucepan: a hot central column of liquid is formed and rises to the surface, while at the sides the cooler liquid descends toward the source of heat. For clarity, the vertical scale over which the convection currents move has been greatly exaggerated.



THE ECLIPSE

the first problem
tackled by astronomers

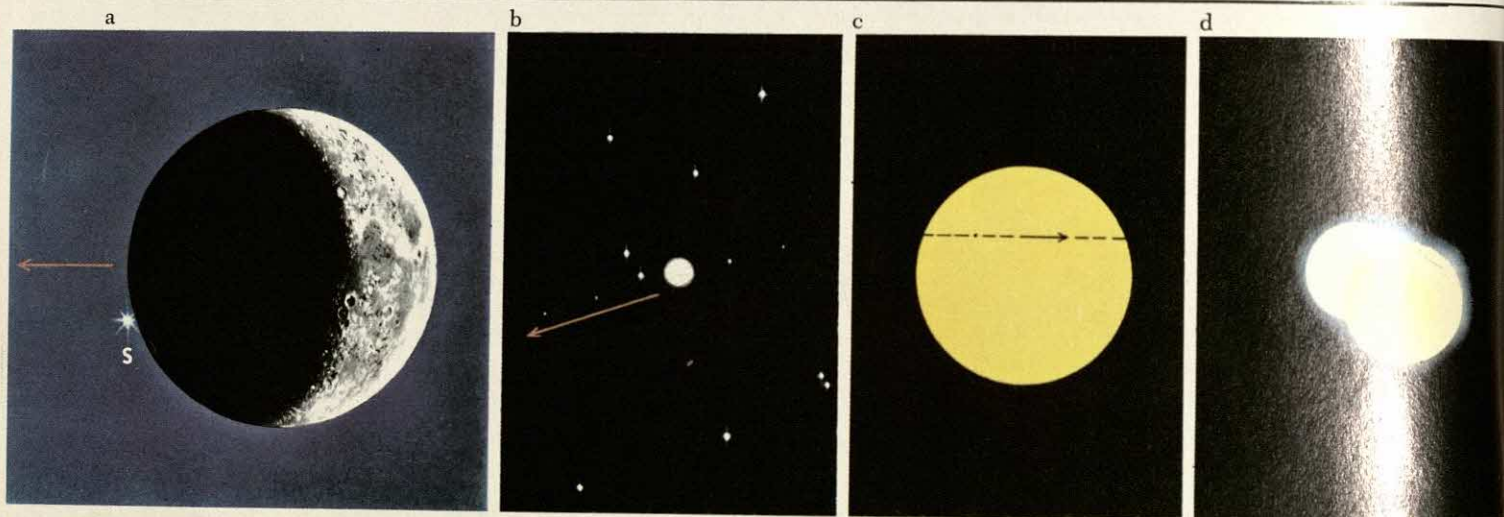
It is easy to imagine why a solar eclipse struck terror into the hearts of primitive men. Without warning, the sun—the great day star that gives light and warmth

to the Earth—begins to disappear. Within minutes, darkness spreads over the face of the sun and its great light grows dim. Imagine the relief early man felt when

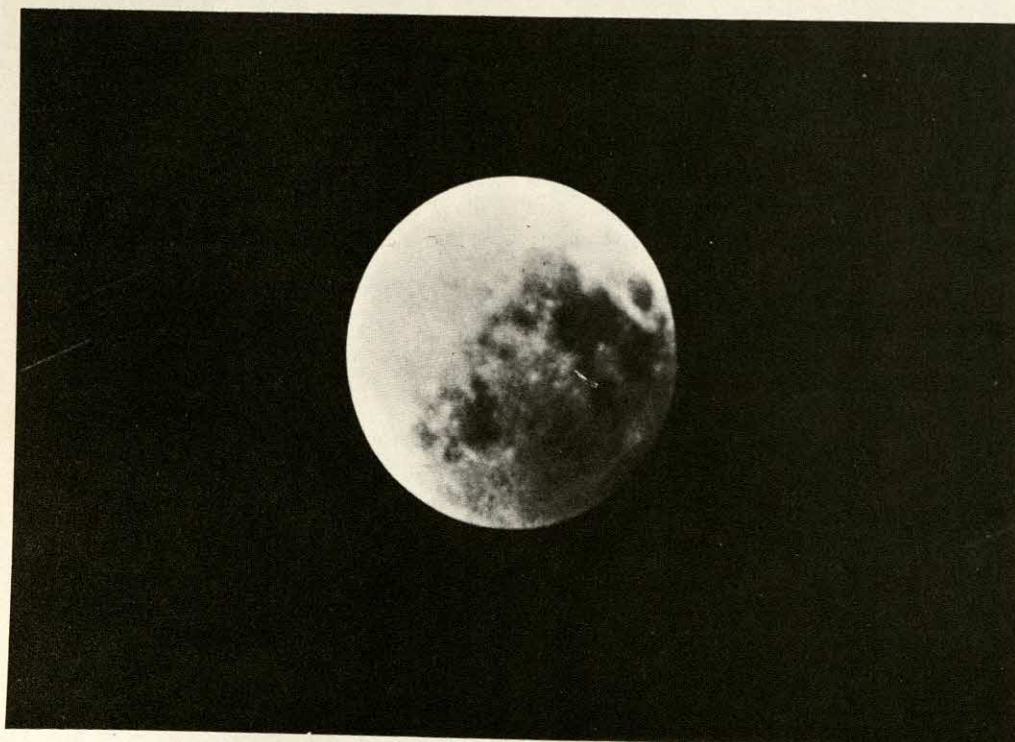
the sun began to reappear!

A total eclipse of the sun is an unforgettable sight, perhaps the most spectacular “show” in the sky. Apart from its

1



f



INTERPOSITIONS, ECLIPSES, TRANSITS, AND OCCULTATIONS—An observer sees stars, which appear fixed in relation to one another, and other celestial bodies such as the sun, the moon, and the planets, which move. When the interposition of one body on another occurs, the first body appears to change position and to hide the second from view. Such interpositions are called by several names, depending on the circumstances.

The interposition of a larger body on a visible self-luminous body such as a star generally is called occultation. Illustration 1a shows how occultation of the moon and a star develops. The moon, shown here in the waxing phase, moves toward the east with respect to the stars. The dark side of the moon then covers the light of the star S in the moon's path. The moment of disappearance is extremely brief (a fraction of a second), and for this reason occultations can be used for precise determinations of time.

Another example of occultation is the interposition of a planet on a star. Illustration 1b shows the occultation of a star, just before its disappearance, by part of the disk of the planet Jupiter. Such an occultation is rare because of the relatively small dimensions of the interposing body. For example, the star Regulus (in the constellation of Leo) undergoes occultation by the planet Venus about once every 900 years.

When a dark body passes in front of a larger, self-luminous body (such as the sun), the phenomenon is called transit. The rare transits of Venus and Mercury across the disk of the sun are observed and studied closely.

visual impact, an eclipse is of great value to astronomers because it gives them an opportunity to carry out observations that are otherwise impossible and are the

determining factors in certain theories. From a scientific standpoint, an eclipse of the sun is more interesting than an eclipse of the moon. Astronomers can

predetermine the exact time of a solar eclipse, making it possible to check accurately the theory of the motion of the moon around the Earth and the motion of the Earth in its orbit around the sun.

During a solar eclipse the sky darkens briefly, making it possible to observe and photograph the stars. Observation of the position of stars near the sun also permits verification of that part of Einstein's General Theory of Relativity that predicts the bending of space and, as a consequence, the bending of the path of luminous rays close to the strong gravitational center of attraction of the sun.

During a solar eclipse it is also possible to take direct photographs of solar prominences, eliminating the need for a spectroheliograph, which produces only a monochromatic image.

The sun's atmosphere in no way resembles that of the Earth. The structure is nonuniform—composed of streamers of luminous gas projected from the solar surface—and the temperature is extremely high. Elements that are solids on the Earth are completely vaporized on the sun. Determination of the chemical composition of the sun's atmosphere and of the temperatures and pressures there is best done from spectroscopic observations at the time of total eclipse.

With a special instrument, a coronagraph, astronomers observe the sun's outer corona—the highest part of the solar corona. Under normal light conditions, such observation is limited to an image of that part of the outer corona that is no more than one radius distant from the sun. During an eclipse, observation can be extended to a distance of five or more solar radii.

The lack of sunlight and other solar radiations during an eclipse permits study of the influence of these radiations on the Earth's atmosphere, particularly the ionosphere. The phenomenon of solar radio emissions can also be studied during an eclipse.

Scientists are able to predict accurately the time of an eclipse by calculations based on a knowledge of how an eclipse occurs.



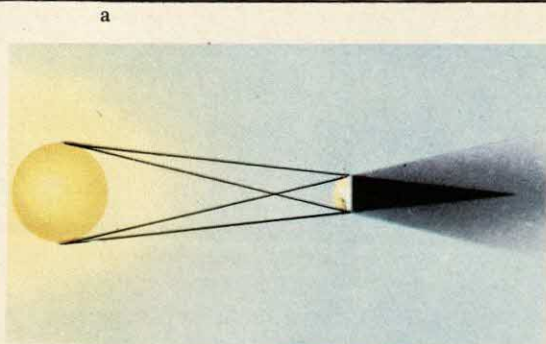
Illustration 1c shows a transit of Venus across the sun, with the broken line and arrow indicating the movement of the planet in relation to the sun's disk. During a transit no appreciable lessening of sunlight is apparent.

The interposition of two bodies whose real or apparent dimensions are comparable is called an eclipse. This occurs in the case of a double star of the eclipsing variable type in which the variability of the star, as seen from the Earth, depends on the interposition of one of the stars on the path of the other. Illustration 1d shows an eclipse of a double star—

the interposition of two self-luminous bodies.

The interposition of the moon between the Earth and the sun causes a solar eclipse. Illustration 1e shows the eclipsed sun. Only a small part of the sun's external atmosphere, the corona, is visible.

The interposition of the Earth between the sun and the moon causes a lunar eclipse. Illustration 1f shows a partial lunar eclipse. Although the shadow of the Earth is projected on the lunar disk, the moon remains visible because some light from the sun still reaches it.

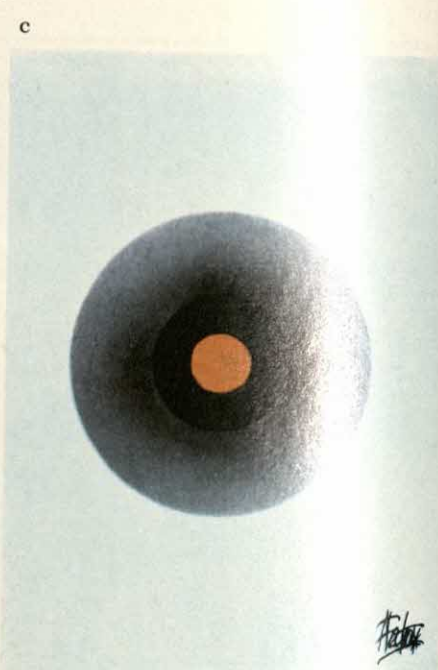
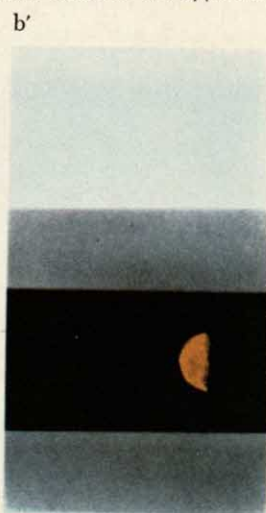
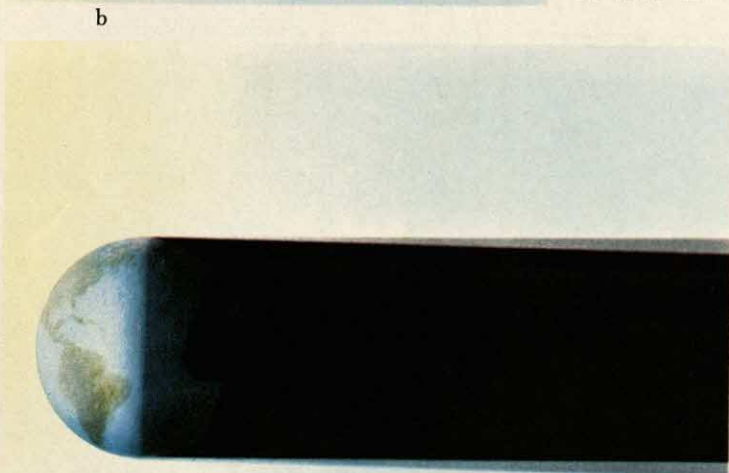


THE SHADOW OF THE EARTH AND ECLIPSES OF THE MOON—To understand how a lunar eclipse occurs, it is necessary to visualize the shadow that the Earth projects into space with the sun as the source of light. Illustration 2a shows the Earth illuminated by the light of the sun. Because the sun is a large source of light, the shadow of the Earth is composed of an umbra (darkest area) and penumbra (lighter area), and is surrounded by space in which the rays of the sun can pass freely.

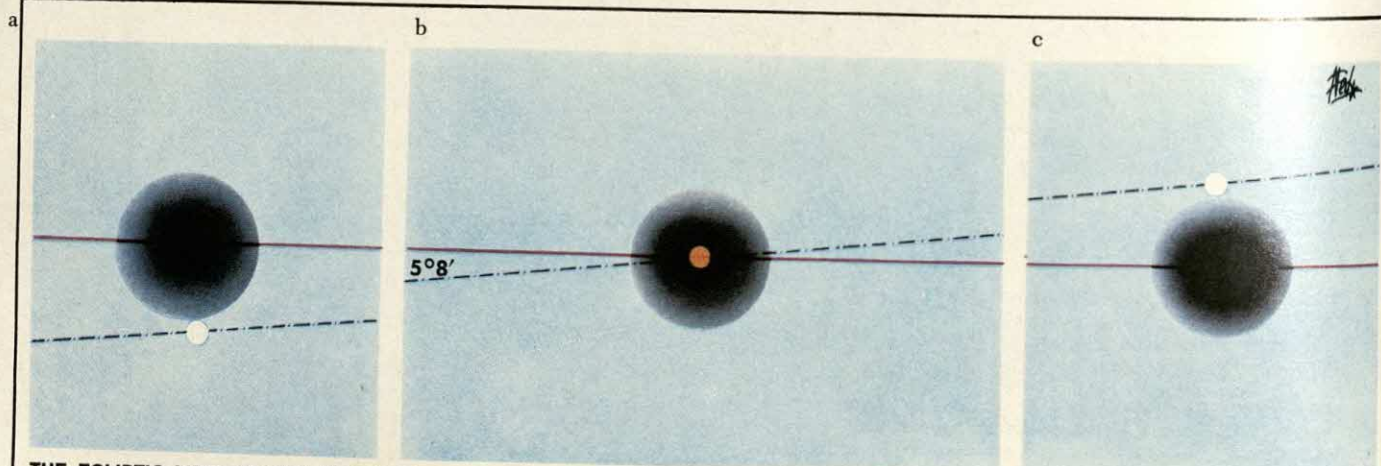
Illustration 2b shows how the rays of the sun strike the Earth. Because the apparent

diameter of the sun's disk is about half a degree, the diameters at the umbra and at the penumbra near the Earth are both almost equal to the diameter of the Earth. At the distance between the Earth and the moon (about 30 times the diameter of the Earth) the diameter of the umbra is much smaller than that of the Earth but still large enough to eclipse the moon (Illustration 2c).

If a section of the shadow of the Earth could be focused on a screen located as far distant as the moon, the moon might appear in the center of the shadow (Illustration 2c).



3



THE ECLIPTIC LIMIT OF THE MOON—If the circular shadow of the Earth could be seen on the celestial sphere, the shadow would be at a point opposite the sun, with the center of the shadow in exact opposition to the sun. The center of the shadow is always on the ecliptic—the great circle of the celestial sphere representing the projection, from the center of the sun, of the Earth's orbit. For a lunar eclipse to occur, the moon must be exactly opposite the sun, that is, in its full-moon phase.

Illustration 3b shows the shadow of the

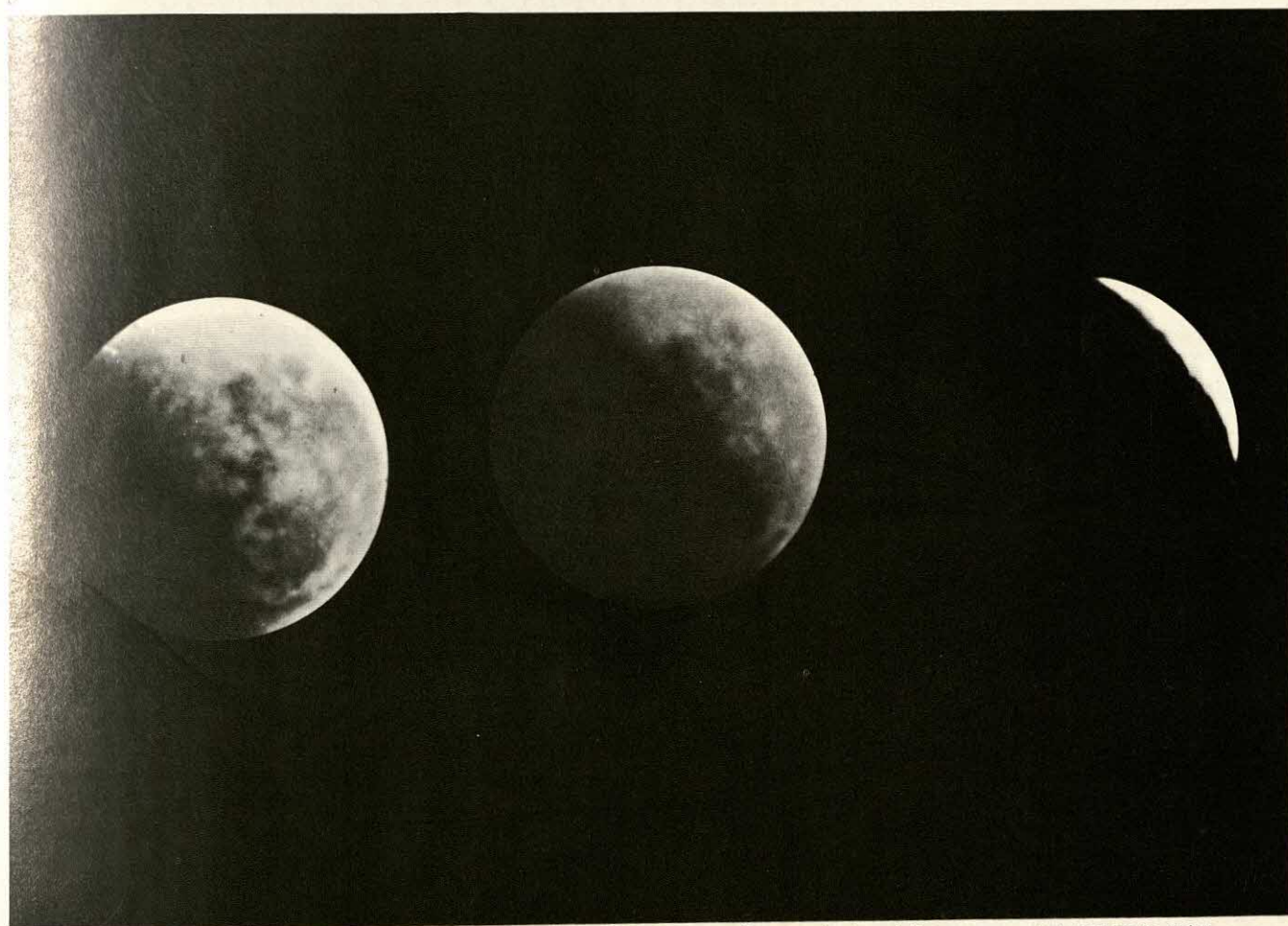
Earth with the moon exactly at its center. This illustrates the maximum phase of a total central eclipse: total because the moon is eclipsed completely and central because the center part of the lunar disk passes through the center of the Earth's shadow. For an eclipse of the moon to be central, the moon must be in its full phase and on the terrestrial ecliptic—a combination of circumstances that occurs very rarely.

The moon moves around the Earth in an orbit that is inclined $5^{\circ} 8'$ to the ecliptic. Therefore, it can reach the full-moon phase either

above or below the terrestrial ecliptic. In most full-moon phases, the moon passes above or below the terrestrial umbra and penumbra. In such cases no eclipse occurs. For a lunar eclipse to take place the full-moon phase must occur when the moon is not more than a certain distance from the node—the intersection of the lunar orbit with the ecliptic. This distance is called the lunar ecliptic limit and does not exceed $12^{\circ} 15'$. Within this limit an eclipse may be only partial. Borderline conditions for an eclipse are shown in Illustrations 3a and 3c.

TOTAL ECLIPSE OF THE MOON—A total eclipse of the moon occurs when the moon approaches full-moon phase within the terrestrial penumbra. The light of the moon slowly fades, and the moon appears darker on the eastern side. The umbra begins to cover the lunar disk from the east. The limits of the penumbra are difficult to observe because the border of the shadow fades into the normal brightness of sunlight. The limits of the umbra are also not defined perfectly, but they

a



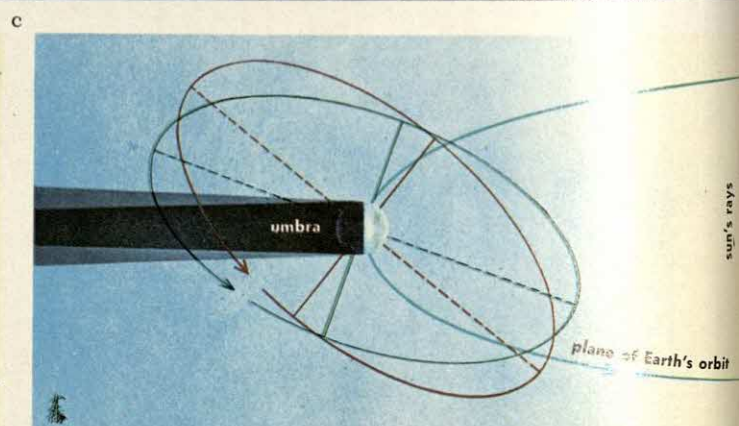
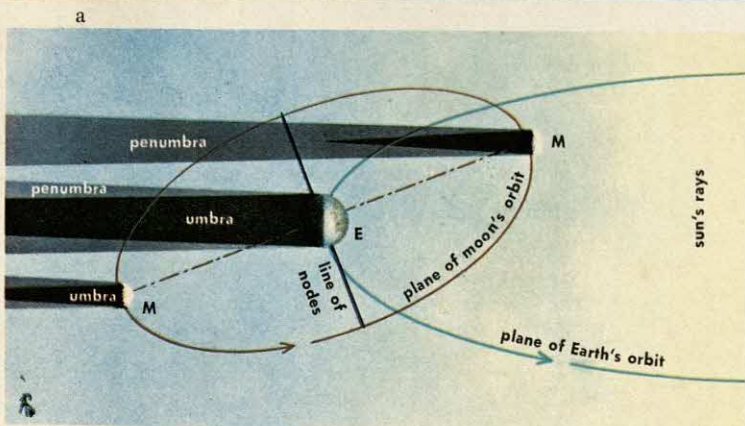
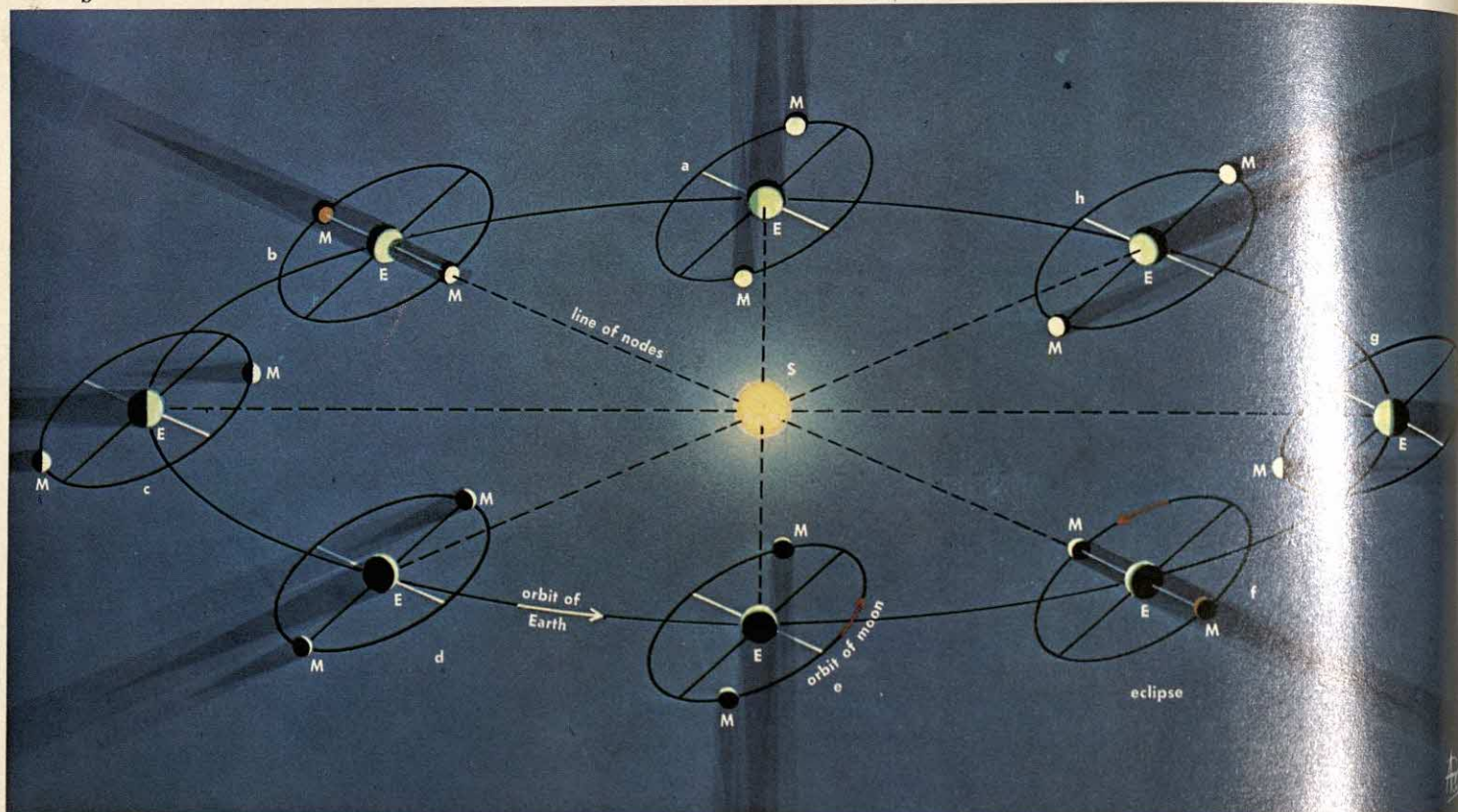
are somewhat easier to distinguish than those of the penumbra. The outline of the umbra on the lunar disk appears perfectly circular—tangible confirmation that the Earth is round.

Even when the terrestrial umbra completely covers the moon's surface, the moon does not appear completely dark. Logically, the moon (Illustration 4a) shown at right in the cone of the umbra, should be completely dark. How-

ever, the moon receives a small amount of light which strikes the borders of the Earth, and the Earth's atmosphere refracts this light toward the axis of the cone of the umbra. This light has passed near the surface of the Earth, where the atmosphere has absorbed rays of short wavelength. Because this light has lost some of its green component and all of its blue and violet, it is reflected by the surface

of the moon as dark bronze in color.

Illustration 4b shows the moon covered gradually by the umbra of Earth. In each photograph the part of the moon that appears luminous is covered completely by the penumbra. Each photograph reveals that the curvature of the outline of the umbra is less than that of the moon's surface, because the size of the umbra at the moon's distance is larger than the moon.



5

ECLIPSES OF THE SUN AND MOON—Illustration 5a shows the relative positions at any given moment of the orbits of the moon and the Earth during the revolution of the Earth around the sun. Because the orbit of the moon is inclined in respect to the orbit of the Earth, the moon is outside the terrestrial shadow in the full-moon phase and there is no eclipse. In the new-moon phase the moon throws no shadow on the Earth and there is no eclipse of the sun.

During the revolution of the Earth around the sun (Illustration 5b), the plane of the lunar orbit, at a first approximation, maintains a fixed orientation in space. The intersection of the plane of the lunar orbit with that of the Earth is called the line of nodes. Eclipses occur only when the line of nodes points almost exactly to the sun as seen from the Earth. (In the case of lunar eclipses within the lunar ecliptic limit, a small tolerance exists.) Points b and f indicate where the line of nodes points to the sun.

Illustration 5c shows the lunar orbit around the Earth. The dotted line marks the intersection of the lunar orbit with the plane of the terrestrial orbit (the line of nodes). This intersection is not fixed; it rotates on the plane of the terrestrial orbit. The retrograde movement

of the line of nodes is caused by the attraction of the equatorial bulge of the Earth on the moon. Because of the constant change in the position of this line, complex calculations are required in predicting an eclipse. After a certain time the line of nodes returns to its original position and eclipses are repeated in the same sequence, a fact that may have been known to Chaldean astronomers of 3,000 years ago. The period of repetition of eclipses, called saros, is 18 years, 11 days, and 8 hours (or 18 years, 10 days, and 8 hours when five leap years occur within the period). During a saros 71 eclipses of the sun and 48 eclipses of the moon may occur, although the number may vary, more or less, by about 5 percent. About 1½ times more eclipses of the sun occur than of the moon. The same number of eclipses does not occur every year. The maximum is seven. Five eclipses of the sun and two of the moon may occur, or four of the sun and three of the moon. Two eclipses of the sun taking place at two successive new moons indicates that during the intervening time, the line of nodes has remained aligned between the Earth and sun. An eclipse of the moon may take place before or after an eclipse of the sun, during the full moon which follows or precedes the new moon when a

solar eclipse occurred. Seven eclipses, two of the moon and five of the sun, occurred in 1805 and again in 1935. This phenomenon will not be repeated until 2160.

A lunar eclipse is not visible from every point on the Earth, but only from those points where the moon, at that moment, can be seen above the horizon. Because an eclipse of the moon lasts for some hours, the eclipse may be visible, in at least some stage, from more than half of the Earth's surface. From some places an eclipse is visible only in its initial or final stages, at the instant of the rising or setting of the moon.

Eclipses of the sun are visible in full from only a very small area of the Earth's surface. Partial eclipses are visible over a larger area, but the area is always much smaller than a terrestrial hemisphere. On an average, from any point on Earth an eclipse of the sun is visible every 360 years. The area from which the eclipse can be observed is often on the ocean. Even in areas where visual observation is possible, meteorological conditions may interfere. Careful studies have been made to determine which solar eclipses offer the best conditions for observation, and expeditions are organized far in advance in order to reach the most favorable spots for viewing the eclipse.

PART 5

- 100 The Structure of Atoms
- 103 Harmony and Disorder
- 106 Matter and Chemistry

CHEMISTRY

substances, reactions,
and energy

Chemistry deals with the properties and behavior of all the materials in the universe. Thus, all nonliving things owe their utility to the chemicals that comprise them—and, most importantly, all life processes result from the interactions between chemicals.

All things can be pure chemical substances themselves or a collection of different substances. A substance is any material that has fixed composition and fixed properties. Table salt derived from ocean water is the same as that mined in many areas of the world; thus, table salt is a pure chemical substance. A stone, a lump of coal, a table, or even a human being fall in the other category in that they are comprised of a number of different substances. Any pure substance can be physically divided into very small particles, and the smallest particle that still has the properties of the collection of particles is either an atom or a molecule.

Molecules are a collection of atoms in definite arrangements according to well-defined physical principles. Thus, chemistry deals more specifically with the isolation of pure substances, the determination of their structures, and the interactions and reactions between chemicals that are responsible for new chemicals and for new sources of energy. As a result, chemists have been able to put to use many materials found in nature for the purpose of medical treatment and the advance of technology in many spheres. Furthermore, where nature does not provide such necessary materials as antibiotics, fire-resistant fibers, and so forth, chemists have synthesized these in the laboratory from other naturally occurring substances. Synthetic substances result from knowledge of chemical reactions.

AN INTRODUCTION TO BASIC CHEMISTRY

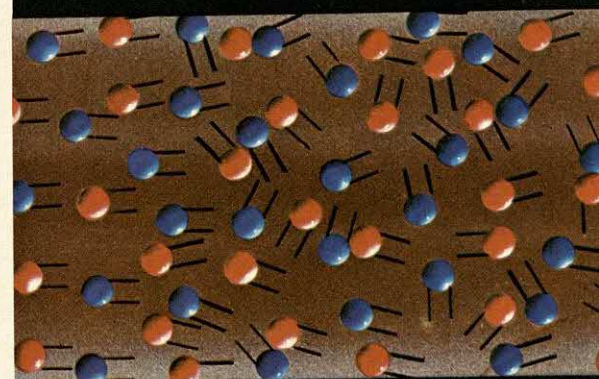
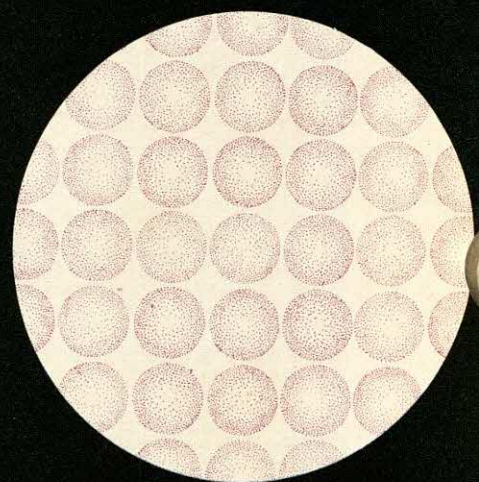
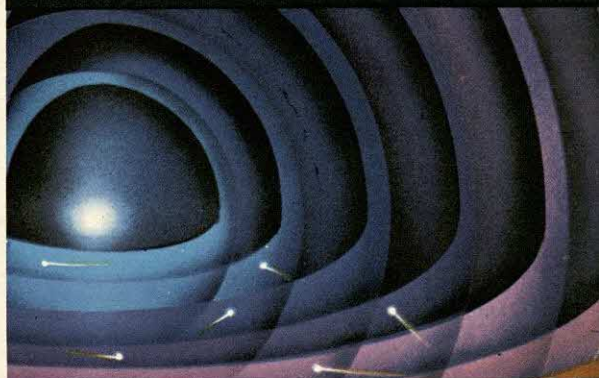
In this introductory section, some of the basic ideas of chemistry are explored. In order to appreciate the properties of chemicals, it is necessary to understand

the structure of the atoms that comprise them. Then, the relationship between atoms and molecules and matter is examined.

Finally, a discussion of the gross properties of gases is presented so that the reader may become familiar with some of the general characteristics of chemical substances. In these preliminary discussions, no account is taken of the variety of pure substances that have been isolated. At present over 100 distinct elements, each having atoms that are characteristically their own, are known. Chemical compounds or molecules that have been formed from these atoms number in the tens of millions. The materials that are combinations of different atoms and different molecules are as numerous as the stars and as diverse as the universe itself.

The first of the three volumes dealing with chemistry (Volumes 10, 11 and 12) examines the different elements and the atoms that comprise them. The second volume concerns itself with fundamental principles of chemical interactions: how molecules are put together, how and why chemical reactions occur, the characteristics of molecules under various physical circumstances, the utility of chemicals, and the energy derived from chemical reactions. In this section particular emphasis is placed on the measurement of physical properties and the analysis of chemical compounds.

The third volume deals with a particular branch of chemistry known as organic chemistry. This is the chemistry of compounds that are derived from the element carbon, which has the unique property of forming chemical bonds with itself, so that many complicated chemical compounds have a molecular backbone made up solely of carbon. (Most plastics and synthetic fibers are long chains of carbon atoms with other groups attached.) Enzymes and vitamins, the catalysts involved in life processes, are also derived from carbon compounds; thus, the study of organic chemistry is vital to an understanding of nature.



THE STRUCTURE OF ATOMS

atomic architecture—
a matter of forces and shells

The structure of an atom has often been compared to that of the solar system—a valid comparison and one that provides a basic understanding of atomic structure. For one thing, the center of an atom—its nucleus—corresponds to the sun's position; and around this nucleus, "orbiting" in precise mathematical relationship to it, are electrons—the equivalents of the planets. Unlike the solar system, however, virtually the entire mass of the atom is concentrated in the nucleus. The electrons, no matter how many, contribute almost no weight to the total atom.

Furthermore, the forces holding electrons to the nucleus are electrostatic in nature. The electrons—negatively charged bits of energy—are attracted by the positively charged protons in the nucleus.

These forces bear no similarity to the gravitational forces at work in the solar system.

Finally, while each planetary orbit around the sun is occupied by a single planet, the "orbits" surrounding an atomic nucleus may contain one, two, or more electrons. Every atom has a number of orbits (or shells) that differ from one another in the average distance of their electrons (in each shell) from the nucleus. Illustration 2 shows a model that represents the shells. Their relative distances from the nucleus can be seen in this visual description.

Of special importance is the structure of the atom at the point farthest from its nucleus. It is this area and its electronic configuration that determine the chemical behavior of the atom.

HOW THE ELECTRONS ARE HELD AROUND THE NUCLEUS

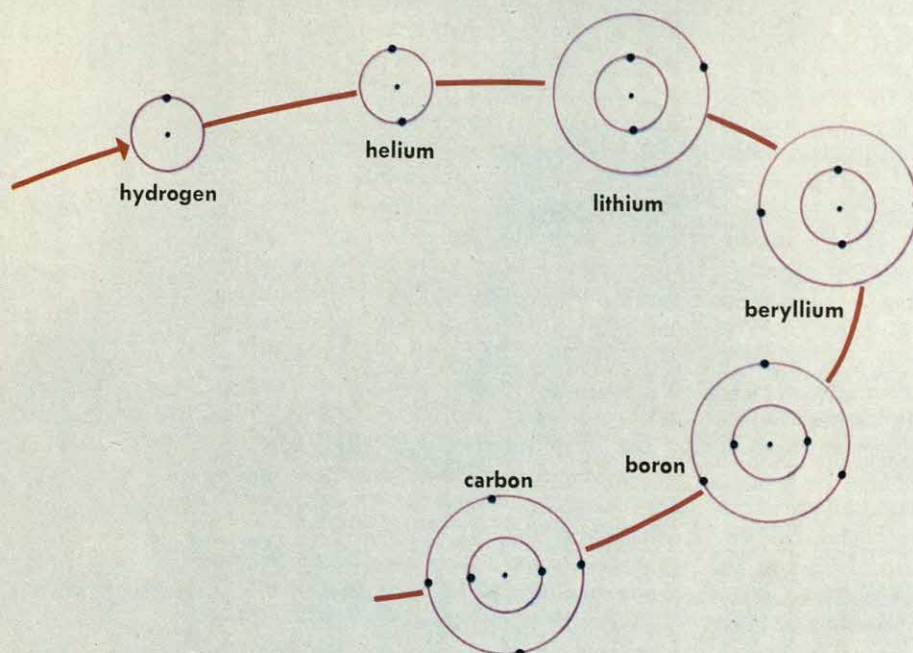
The extent of the positive charge on an atom's nucleus is a result of the number of protons in the nucleus. In electrically neutral atoms, each positive nuclear charge is balanced by the negative charge of an electron; thus, the number of electrons around a nucleus depends on the number of protons in the nucleus. While the sum of protons and neutrons (subatomic particles having no electrical charge) in a nucleus constitutes the atomic weight of the atom, the electrons determine its chemical properties. Because of the proton-electron interrelationship, two atoms differing by only one proton are different elements, each with a distinct set of properties.

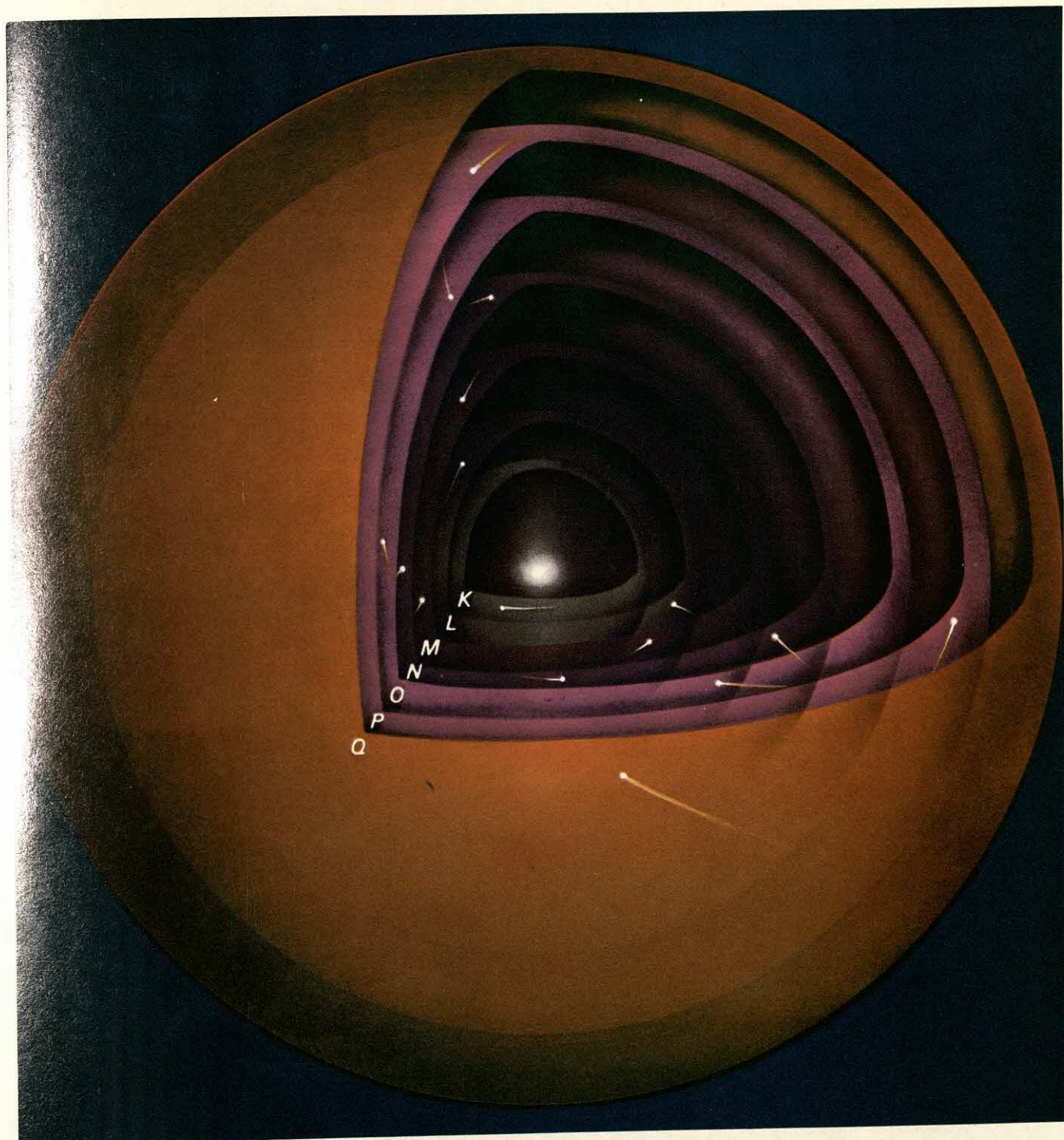
THE BUILDING OF ATOMS—Electrons are arranged around their nucleus in successive

orbits or shells. The first shell, closest to the nucleus, holds a maximum of two electrons.

The second holds one to eight. Electron configuration in the first six elements is shown.

1





CUTAWAY VIEW OF A URANIUM ATOM—The average distances of electrons in each orbit are shown as concentric, spherical shells with

the nucleus as a common center. Uranium's 92 protons are balanced by 92 electrons, the latter limited according to the equation

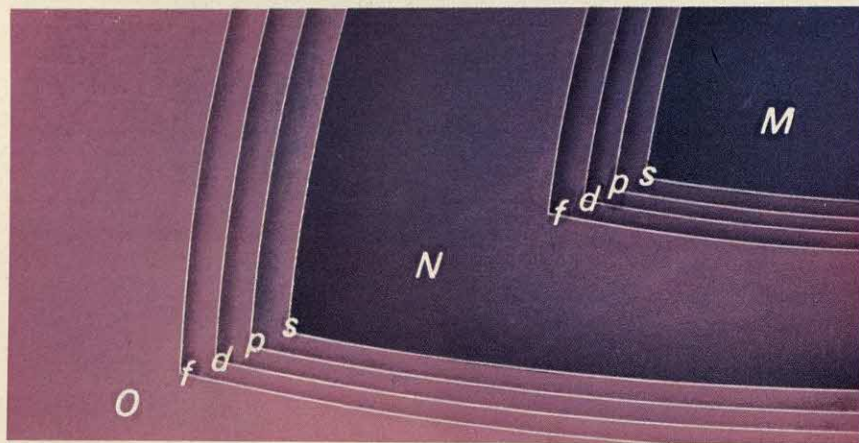
$e = 2n^2$, where e is the maximum number of electrons and n is the number of the shell.

Hydrogen, for example, has just one proton-electron pair. Adding a single proton and its accompanying electron results in another element, helium. Further up the "ladder" of elements, the iron atom has 26 protons in its nucleus and 26 electrons spinning in their shells; an

atom of uranium (the heaviest natural element) is made up of 92 protons and 92 electrons. The number of protons, in fact, determines what chemists call an element's atomic number; thus, the atomic number of hydrogen is 1, that of iron is 26, uranium is 92, and so forth.

ELECTRONS AROUND THE NUCLEUS

To understand how electrons are arranged around the nucleus of an atom, imagine the nuclei of all the elements lined up next to each other without their



SUBLEVELS IN A URANIUM ATOM—Every shell has a number of subshells, or orbitals, labeled **s**, **p**, **d**, and **f**. The average distance of electrons from the nucleus in each subshell of a given shell is shown. However, the actual shapes of each of these subshells differ from one another according to the laws of quantum mechanics.

LITHIUM FLUORIDE MOLECULE—LiF.

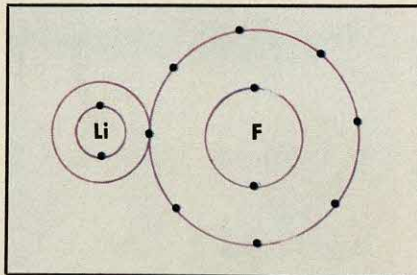
electrons. Each nucleus is able to attract a number of electrons equal to its protons. Hydrogen, with one proton, is the first element in the series; if an electron is allowed to approach this nucleus, it will go into the orbit closest to the nucleus. The diameter of this orbit, or shell, is on the order of one hundred millionth of a centimeter (about 2.5 cm equal 1 in.).

What happens when an electron approaches a helium nucleus, which has two protons? The electron will also go into the shell closest to the nucleus in exactly the same way as did the hydrogen electron. The difference here is that only one of the positive charges of the helium nucleus has been neutralized; another electron approaching the incomplete atom will also go into the shell closest to the nucleus.

If the same operation were performed with the three-proton nucleus of the lithium atom, the first two electrons would arrange themselves in the same manner as with helium. The third would go into a larger, more exterior shell.

Continuing this procedure—with the atomic nuclei having more and more protons—the electrons will arrange themselves according to a simple rule: The maximum number of electrons that can be contained in any one shell is given by $2n^2$, where n is the number of the shell. The first shell (nearest the nucleus) is

4



known as the K shell. Next is the L shell, then M, N, O, P, and Q, the seventh shell and the farthest from the nucleus. Illustration 2 clearly shows these shell relationships.

Thus, the K shell, where $n = 1$, can accommodate only 2 electrons; L ($n = 2$) can take 2×2^2 or 8 electrons; M ($n = 3$) is filled when there are 2×3^2 or 18 electrons. This process can be continued until there are 92 protons and an equivalent number of electrons—the end of the series of natural elements. Beyond this, up to 104 protons, are the man-made elements. (Even heavier matter could be produced, but its atoms would be so unstable that they would change immediately into lighter materials.)

SHELLS, SUBLEVELS, AND THE ARRANGEMENT OF ELECTRONS IN SPACE

The “shells” in which the electrons spin around the nucleus is merely a descriptive term to give an approximate idea of electron arrangement in atoms. A more accurate picture would show that the electrons in shells L through Q are not all placed exactly in their respective shells. Rather, they are located in subshells, or orbitals, which are labeled **s**, **p**, **d**, and **f**.

The distance from the nucleus of electrons in each of these subshells (or orbi-

tals) differs as shown in Illustration 3. The electrons in the **s** subshells are closer to the nucleus than the electrons in the **p** subshells, and so forth. It is important to note that the shapes of the subshells that accommodate these electrons are substantially different from one another: **s** subshells are spherical, while **p** subshells are dumbbell-shaped; and **d** and **f** subshells have more complex shapes. These shapes are derived from the mathematical laws of quantum mechanics.

Finally, far from standing still, electrons can be “found” at any point on their assigned orbitals at a given instant. Simply stated, there is no single point at which an electron rests.

STRUCTURE AND CHEMISTRY OF THE ATOM

The next step is to comprehend the relationship between atomic structure and chemical behavior. Once an overall picture of the atom is understood, the laws of chemistry are more easily understood.

A complex atom, such as aluminum, contains 13 electrons: two in the K shell, eight in L, and three in M. The electrons in the K shell which is closest to the nucleus, are bound most strongly to the nucleus—a statement true for all atoms. The electrostatic binding forces act to a lesser degree on the L shell, and still less on M shell electrons.

If the aluminum atom is bombarded with another atom, one or more electrons can be detached from it. If the force of the bombardment is weak, as in ordinary chemical reactions, the outermost M shell electrons will be displaced. A violent bombardment, on the other hand, causes electrons in the inner shells to be dislodged, although this can be achieved only under very special conditions. It is also possible to detach electrons from an atom with a high-intensity electric force. The first electrons to be released will always be from the outermost shell.

Imagine two atoms of different elements being forced close to one another. As the distance between them decreases, the outermost electrons of the first atom come under the influence of the electrostatic forces of the other, and vice versa. At this point, the forces create a “bond” between the two atoms. The ability to bond depends entirely on the electrons in the outermost shell—they alone are responsible for atoms being able to unite with each other, and are therefore responsible for the chemical behavior of atoms.

HARMONY AND DISORDER

Dalton's, Graham's,
and Henry's laws

A gas, whether it is the atmosphere as a whole or one of the many gases that make up the atmosphere, is a collection of particles in continuous motion. These particles, or molecules, collide with one another and with the walls of any container in which they may be confined. The collision of gas molecules against such a barrier—such as a rigid steel cylinder, a pliant rubber balloon, or a pair of lungs—creates pressure that can be measured. The amount of pressure is independent of the chemical makeup of the gas; a mixture of gases, such as the atmosphere, or a single gaseous compound, like carbon dioxide, will exert a given amount of pressure as a function of the number of collisions between molecules or between molecules and the walls of a container. This fact is explained by the kinetic theory of gases, of which the main points are:

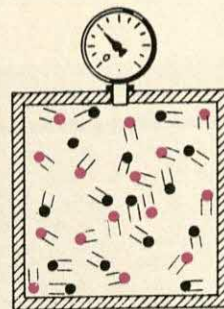
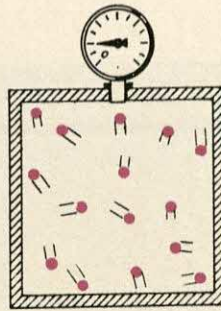
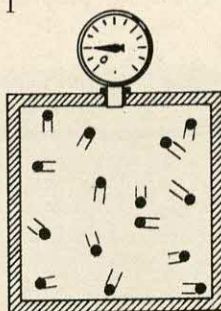
1. A gas is not a continuous fluid, but consists of a number of very small particles of identical sizes—molecules—that do not interact with each other in any way;
2. The size of the molecule is negligible with respect to the average distance between molecules in a gas;
3. Collisions between molecules or between molecules and the walls of a container demonstrate perfect elasticity. The result of molecular impact on containing walls is the gas pressure.

These three characteristics of gases are rarely found in real gases. In the study of gases, however, it is convenient to imagine an "ideal" gas in order to generalize about the behavior of all gases. Dalton's, Graham's, and Henry's Laws apply to ideal gases. The application of the laws to analysis of real gases requires modifications.

DALTON'S LAW

In a closed container holding a mixture of different gases—oxygen, carbon dioxide, and nitrogen, for example—each will exert a pressure of its own against the walls of the container. The sum of these individual pressures will, in turn, represent the total pressure on the container. This is, in fact, the basis of Dalton's law (named after John Dalton the British chemist and physicist), which states that the total pressure exerted by a mixture

1



THE SUM OF TWO PRESSURES—According to Dalton's law of partial pressures, the pressure exerted by a mixture of gases in a con-

tainer of given volume is equal to the sum of the individual pressures that each gas would exert by itself in the container.

of gases is equal to the sum of the partial pressures of the gases in the mixture. (Partial pressure means that pressure exerted by a gas when it is the only gas in a container.)

The formula for expressing Dalton's

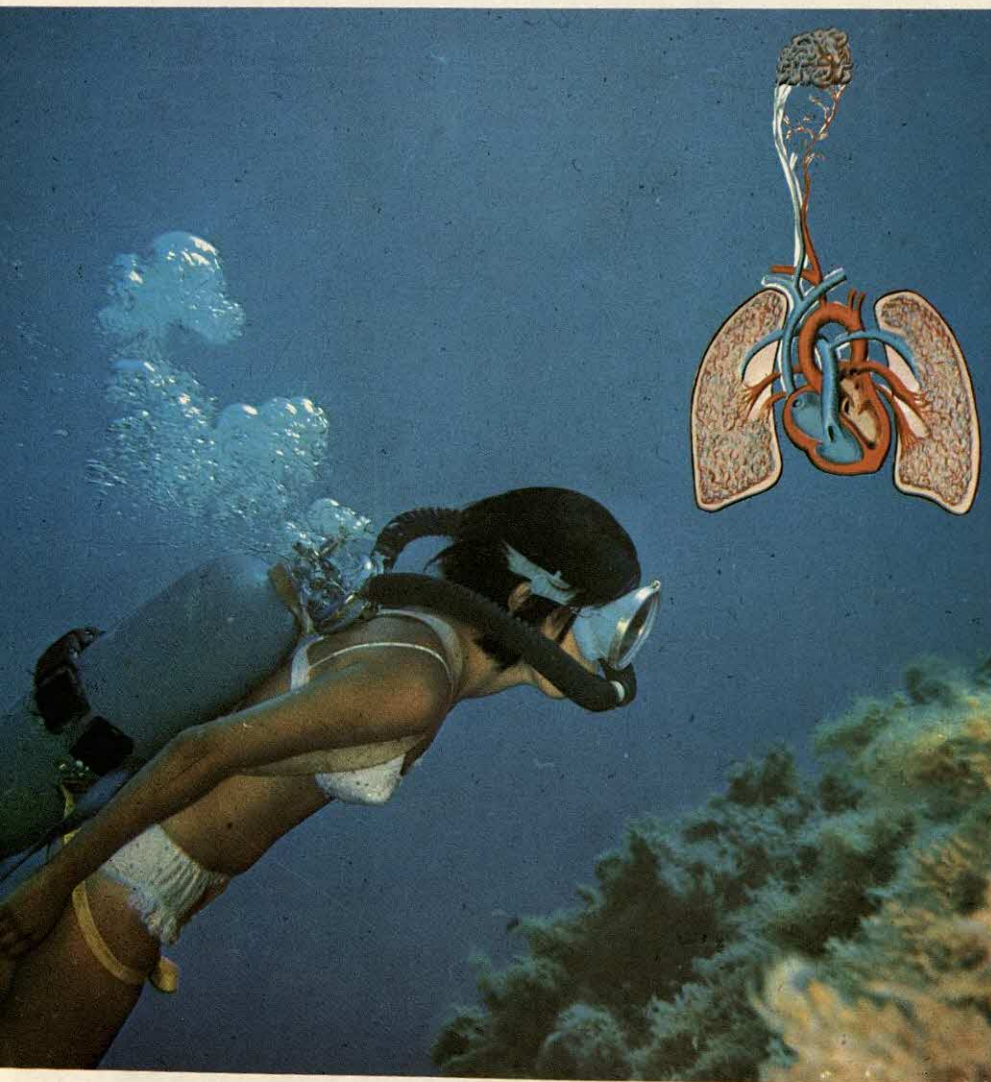
Law is $P = p_1 + p_2 + p_3 + \dots + p_n$, where P is the total pressure of the gas mixture and p_1 , p_2 , p_3 , and p_n are the partial pressures of the constituent gases. Illustration 1 shows this law applied to a mixture of two gases.

SOLUBILITY OF GAS IN LIQUID—The "sparkle" and "pop" in carbonated water are due entirely to a gas under pressure in liquid. When a bottle of soda is opened, the pressure on the liquid is decreased, and the gas rises

to the surface in the form of bubbles. Thus, a decrease in pressure results in a corresponding decrease in solubility of a gas—the essence of Henry's law.

2





more rapidly than a heavy one (assuming that both are at the same temperature and pressure). This variation in gas diffusion rates is explained by Graham's law (named for Thomas Graham, the British chemist), which states that the rate of diffusion of a gas is inversely proportional to the square root of its molecular weight. Mathematically, this law is expressed:

$$R = \frac{\text{constant}}{\sqrt{m}},$$

where R is the rate of diffusion, m the molecular weight of the gas, and the constant is an invariable number—1, for example.

A practical application of Graham's law is seen in the separation of the isotopes uranium-235 and uranium-238. In its natural state, uranium contains 99.3 percent ^{238}U and 0.7 percent ^{235}U , although only the latter is suitable for use as a fuel in nuclear reactors. Thus physicists, in searching for a way to separate the ^{235}U from the "unwanted" ^{238}U , turned to Graham's law, which provided the basis for one of the most efficient methods of uranium separation. Natural uranium ore is chemically converted to uranium hexafluoride, UF_6 , which is a gaseous mixture of the two fluorides $^{235}\text{UF}_6$ and $^{238}\text{UF}_6$. Under special conditions of pressure and temperature, the mixture is passed through a porous membrane. Since the $^{238}\text{UF}_6$ is the heavier of the two compounds, it diffuses at a slower rate than the $^{235}\text{UF}_6$. Thus, the mixture coming through the membrane is rich in ^{235}U . In order to obtain a useful concentration of ^{235}U , the operation must be repeated thousands of times because the difference in molecular weights of the isotopes is very slight.

This example shows how the laws of gases aid in solving practical problems as well as explaining everyday occurrences.

HENRY'S LAW

Graham's law and Dalton's law deal with gas diffusion and gas pressure, respectively. In a sense, both these properties are referred to in a third law of

SCUBA DIVING AND HENRY'S LAW—The pressure exerted on a diver increases according to depth. The result is an increasing amount of air "dissolving" in the blood. While the air's oxygen is readily combined in the blood, the nitrogen in the air collects in the nerve tissue. A slow ascent allows the collected nitrogen to escape through the lungs

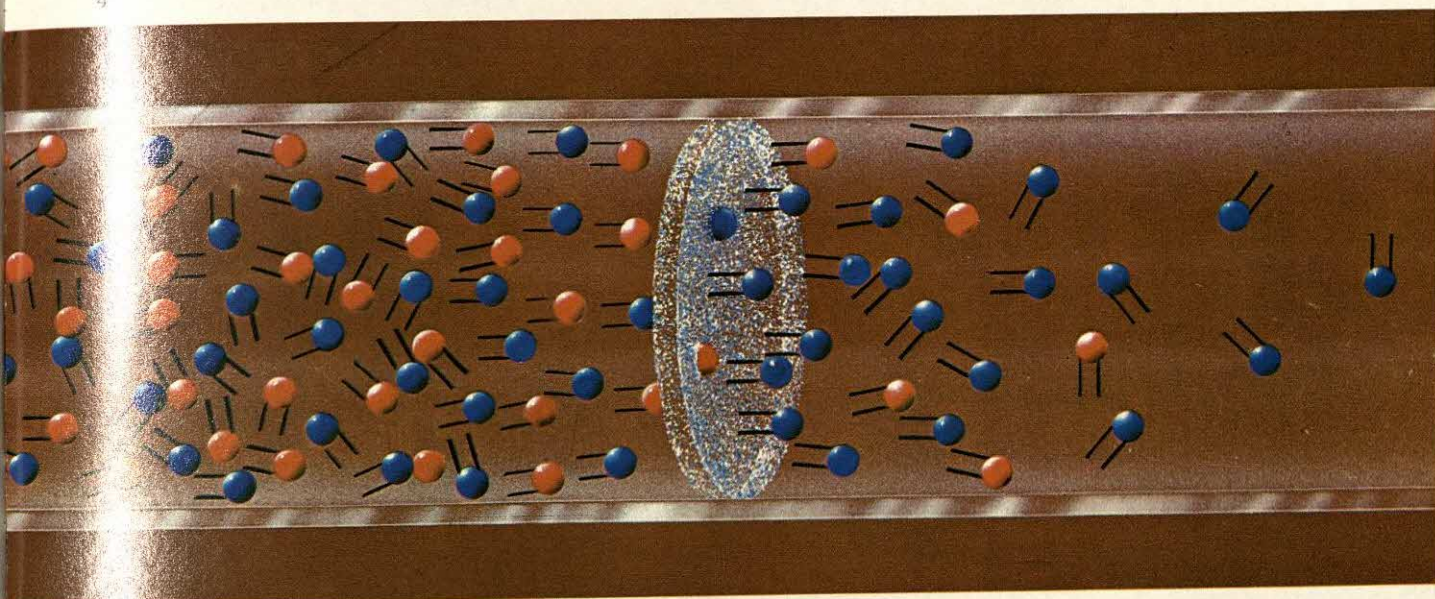
by way of the bloodstream. Surfacing too rapidly, however, with a corresponding decrease in pressure, prevents the blood from accommodating large quantities of nitrogen released by the tissues. Some of the gas may remain in the form of small bubbles, causing permanent or fatal damage to the nervous system.

GRAHAM'S LAW

A corollary to Dalton's law is that gases tend to fill completely any amount of space available to them. Here it is necessary to explain the diffusion behavior of a gas, for it is by the process of diffusion

that gases occupy space. Burning coal provides an everyday example of a gas diffusing into the atmosphere; the odor that comes from a coal fire is caused by the release of sulfur dioxide into the air.

Each gas diffuses at a given rate. Logically, a light gas will expand or diffuse



DIFFUSION OF A GAS MIXTURE—According to Graham's law, the rate of diffusion of a gas varies with its molecular weight. Thus,

a heavy gas will diffuse at a slower speed than a light one. The illustration shows this diffusion of a mixture of two gases of different

molecular weights through a porous membrane.

gases, known as Henry's law (named after William Henry, the English physician and chemist). A third property—the solubility of a gas in a liquid—is also expounded in Henry's law, which states that at a constant temperature, the solubility of a gas in a liquid is proportional to the pressure exerted on the gas. Basically, the greater the pressure on a gas in a liquid medium, the greater amount of gas will “dissolve” in the liquid (assuming that the two components are not chemically reactive).

This third basic law of gas behavior is graphically illustrated by the example of a scuba diver. On land, the pressure on the diver is constant (to the extent of about 15 pounds per square inch at sea level). But once the diver is in the water, the pressure increases in relation to the depth of his dive. The result, according to Henry's law, is an increase in the quantity of air (from the scuba tanks) forced into and “dissolved” in the diver's blood. The oxygen content of the air is readily accommodated by the blood, but the nitrogen—the major constituent of air

—is not. Instead, the nitrogen is carried by the blood plasma to all parts of the body, and tends to accumulate in nerve tissue.

As the diver descends, the increasing pressure from the weight of the water above him drives more and more nitrogen into the tissues. There is no problem so long as the pressure remains constant, or increases (within limits), or does not rapidly decrease. But if the diver surfaces quickly, with a corresponding decrease in pressure, the nitrogen will be released from the nerve tissues into the bloodstream too fast for accommodation. When this happens, the plasma is not equal to the task of redissolving all the nitrogen for exhalation through the lungs. Thus, part of the gas will be left behind, undissolved in the nerve tissue, creating pockets of pressure that may result in severe or fatal injury to the nervous system.

Diagrammatically, this is what occurs when a diver returns to the surface at a speed safe enough to maintain equilibrium between nitrogen intake and output:

lungs ↔ plasma ↔ nerve tissue

A rapid ascent, on the other hand, alters this balance; less nitrogen can be expelled by way of the plasma to the lungs, so that small nitrogen bubbles collect in the tissue. Represented schematically:

lungs ↔ plasma ↔ nerve tissue

In this instance, the speed at which the gas escapes is reduced in relation to the quantity of gas present in the system.

While each of these laws was formulated to deal with ideal gases (those gases for which there is no attraction between molecules), practical application is obviously possible. In fact, as long as gas molecules are not forced into close proximity by abnormal conditions, they will conform to the laws as stated. In normal circumstances, the attraction between gas molecules is slight; nonetheless, modifications are sometimes necessary, for no gas will conform in all instances to an “ideal” law.

MATTER AND CHEMISTRY

of what are a stone, a flower, ourselves composed? chemistry gives many of the answers.

Matter is anything that can be seen, tasted, or touched. Air is matter, and so are lightning, rocks, and flowers.

From time immemorial, men have wondered about the origin and composition of matter. Many early scientists held fast to the idea that all substances were made up of minute, invisible particles, with each particle imperceptible to man's senses, and that each substance consisted of a few basic elements. The Greek philosopher Democritus, who lived during the fifth century B.C., was the first to advance this theory. He even theorized the existence within all matter of indivisible particles, which he called atoms. According to Democritus, "The only existing things are the atoms and empty space; all else is mere opinion." He held that the individual atoms were to be described solely in terms of geometry and motion. His atoms were innumerable, indestructible, and in motion.

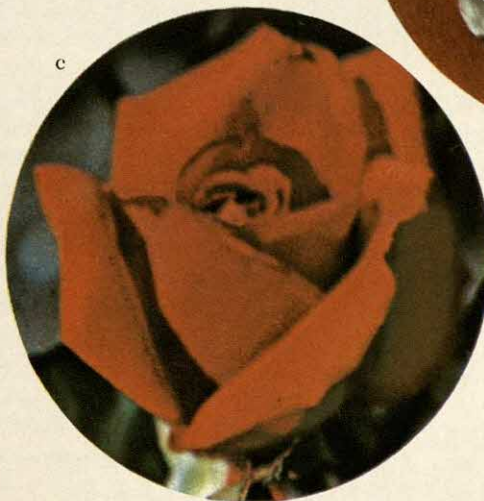
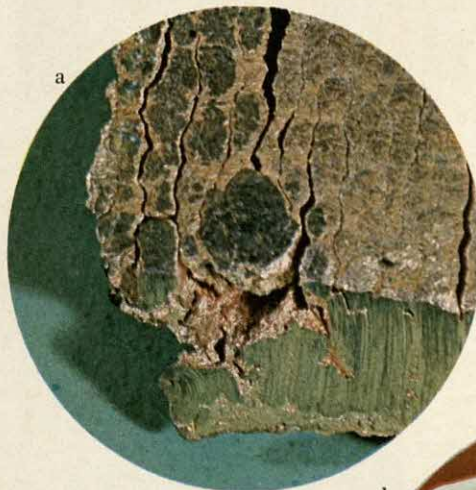
One property of matter observed by ancient man was its ceaseless transformation. A log, for example, turned to earth (ash) and hot air as it burned; but until recently man was unable to formulate any precise laws as to how such transformations came about.

During the last two centuries, however, the study of matter and its transformations has led to the formulation of certain laws about matter. Now it can be said with absolute certainty that matter is composed of a limited number of fundamental elements. Scientists know, too, that all the transformations of matter that can occur depend on the reactions within the smallest particles—the atoms—into which matter itself can be subdivided. A study of chemistry, therefore, logically begins with a study of atoms, because the laws of chemistry are founded on their properties and characteristics. An imaginary magnification of three very common objects—metal (a piece of copper), a sodium chloride crystal (table salt), and a flower (rose)—effectively discloses that matter is made up of combined atoms, each of which contains electrons and a nucleus.

THREE OBJECTS MADE UP OF DIFFERENT SUBSTANCES—Illustration 1a shows a bright, solid, opaque lump of copper with characteristic coloration. Illustration 1b shows a crystal of table salt. It is translucent, brittle, light in weight, and colorless. The rose petals in Illustration 1c are opaque, colorful, light, and flexible. To the unaided eye, these three ob-

jects reveal nothing in common, even if they do resemble each other in certain properties. In order to discover their basic structure, it is necessary to imagine how they would look under a magnification stronger than is presently attainable, even with the electron microscope.

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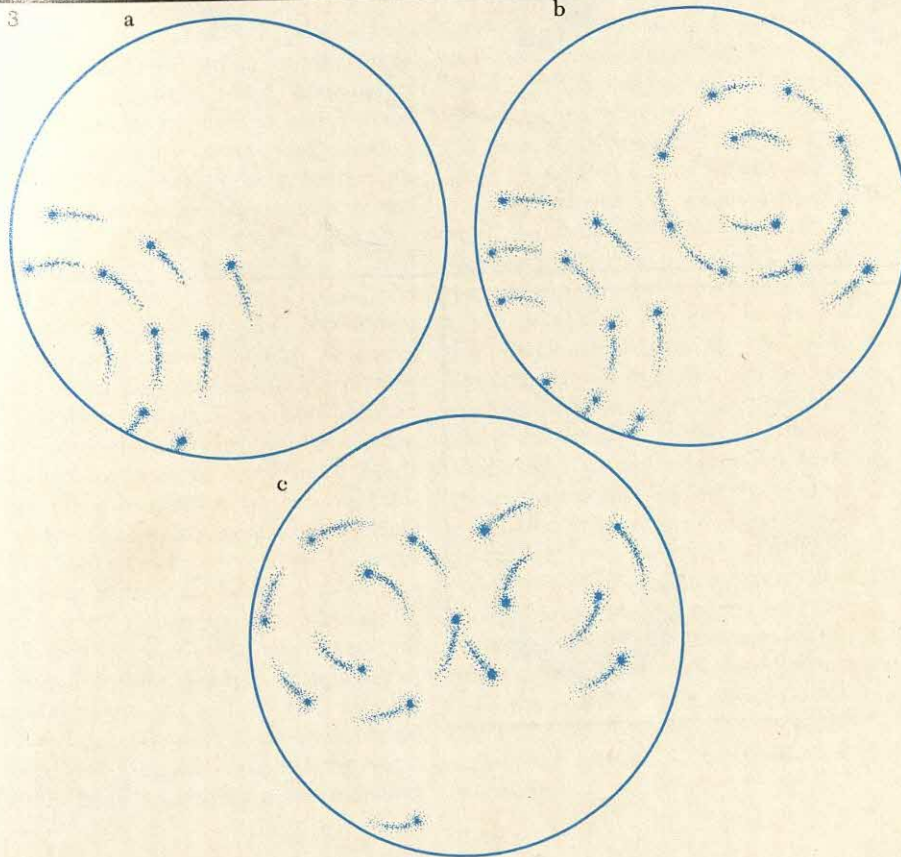
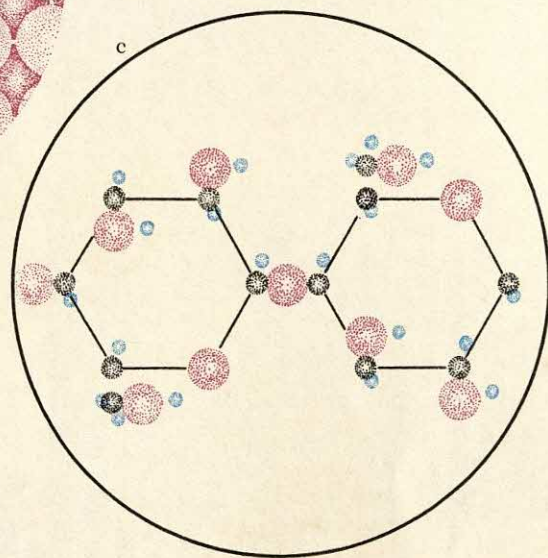
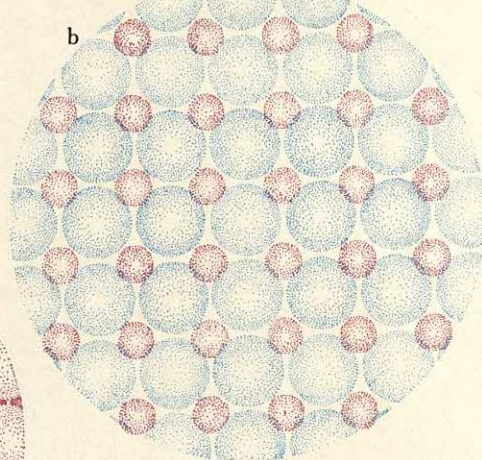
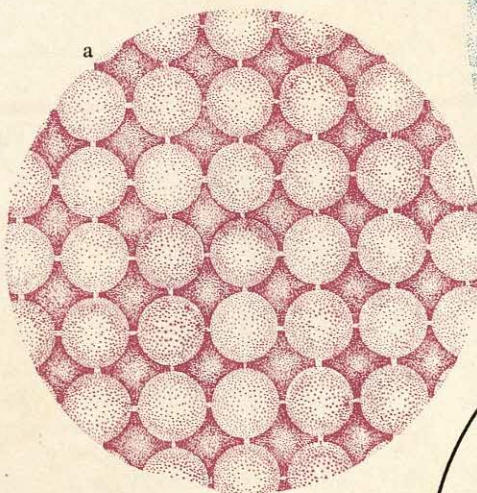
MAGNIFICATION 20,000,000 X: SPHERICAL NATURE OF OBJECTS—The piece of copper (Cu) is made up of small, neatly arranged spheres, equal in size and shape (Illustration 2a).

The sodium chloride crystal (NaCl) is also made up of small spheres, but of two different kinds: large ones (the chlorine ion Cl^-) and small ones (the sodium ion Na^+). The diameter of the smaller spheres is about half that of the larger, with the small spheres occupying the spaces left among the large ones. Neither the large nor the small spheres are sodium chloride; the smallest particle of sodium chloride consists of two spheres, one large and one small.

The rose petal contains spheres of three different kinds, arranged at the vertices of adjacent polygons (Illustration 2c). The smallest particle of a rose petal—cellulose—is formed by a series of more than 1,000 hexagonal groups (molecules) into which the spheres are clustered.

The spheres revealed by the imaginary magnification are atoms. Every substance—whether copper, salt, or cellulose—is composed of atoms, and the atoms of each of these substances differ from those of each of the other two. Yet despite the vast number of substances making up the universe, all are formed by only about 100 kinds of atoms.

A substance made up of only one kind of atom is an element, and a substance made of two or more atoms is a compound. Copper is an element; salt and cellulose are compounds. Further imaginary magnification reveals the structure of atoms—the basic “building blocks” of all substances.

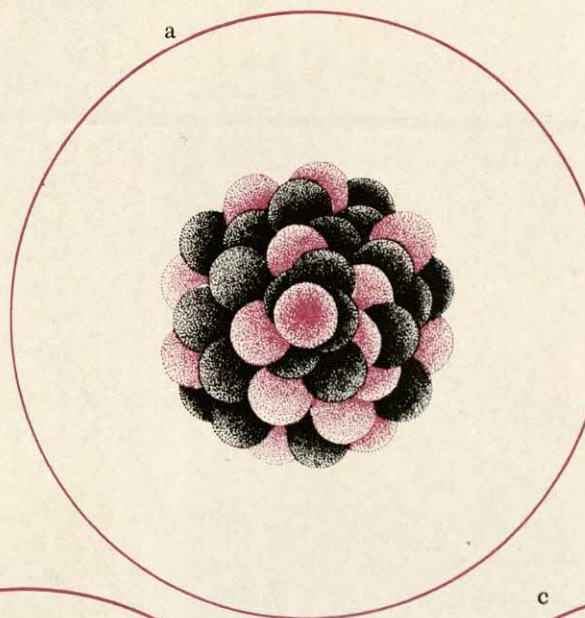


MAGNIFICATION 100,000,000 X: THE STRUCTURE OF THE ATOM—At this magnification a copper atom (Illustration 3a) appears as a complex of particles clustered around a point (the nucleus), somewhat like the planets around the sun in the solar system. In contrast to the planetary system—in which only one planet revolves in each orbit—these particles, which are electrons, can be clustered in groups on any particular orbit according to well-defined physical laws.

The sodium atom has 11 electrons revolving around its nucleus, while the chlorine atom has 17 electrons (Illustration 3b).

In cellulose ($\text{C}_6\text{H}_{10}\text{O}_5$), 6, 1, and 8 electrons orbit the nuclei of a carbon atom, a hydrogen atom, and an oxygen atom, respectively (Illustration 3c).

Electrons are diminutive particles charged with negative electricity. Because the electrons keep to their orbits around a nucleus, it can be deduced that each nucleus holds a positive charge of electricity—for only a positive charge is capable of keeping a negative charge attracted to it. In a sense this attraction between charges of opposite sign is somewhat equivalent to the gravitational attraction that keeps the planets orbiting around the sun. These illustrations, however, do not show the atomic equivalent of the sun—the nucleus.

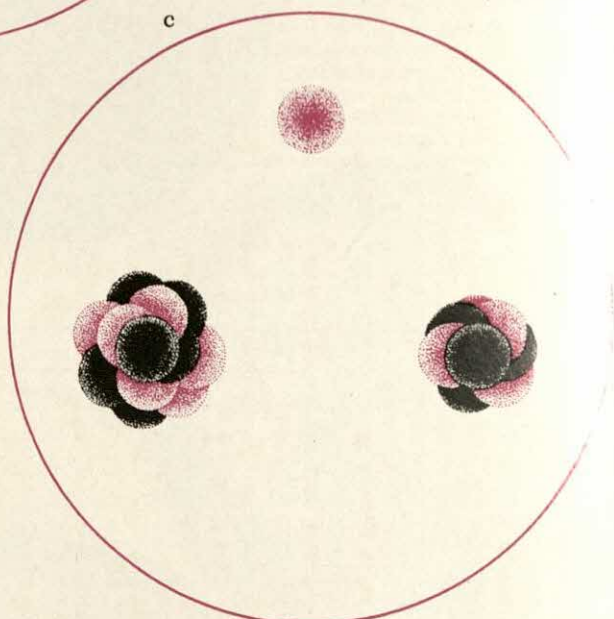
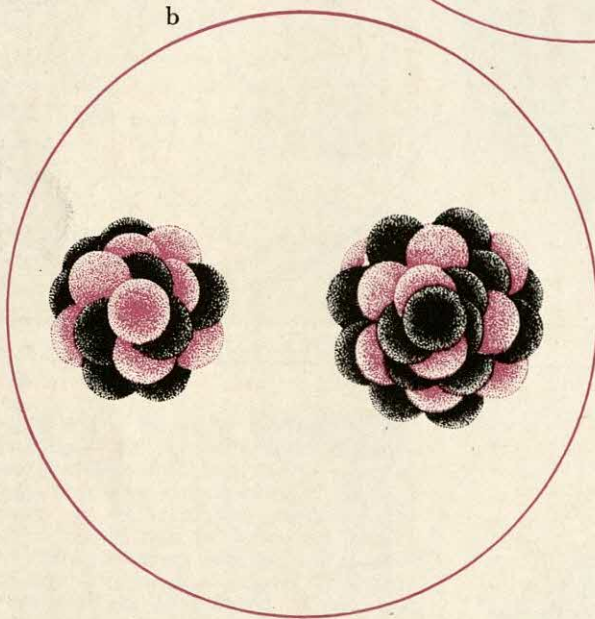


MAGNIFICATION 10,000 BILLION. NUCLEI AND ELEMENTAL PARTICLES—Because of the limited magnification of even the most powerful microscope (about 1,000,000 X), no one has ever seen an atomic nucleus. The following illustrations are, therefore, theoretical.

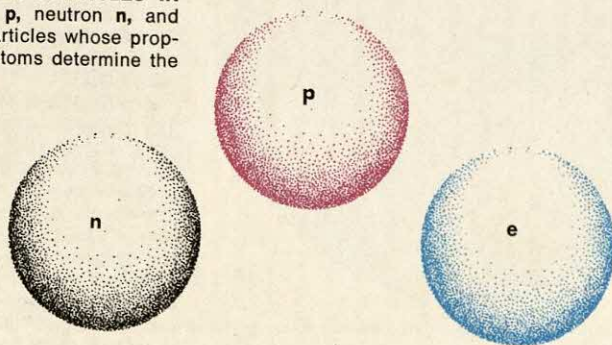
Illustration 4a shows the nucleus of a copper atom. The nucleus appears to consist of positively charged particles (pink) and uncharged particles (black). The first are protons and the second are neutrons. They are of almost equal weight and together make up the weight of the nucleus.

Illustration 4b shows the nuclei of chlorine and sodium atoms. Here, the atomic mass is concentrated in the nuclei; the electrons have a relatively negligible weight, about $1/1837$ of the mass of the hydrogen atom.

Illustration 4c shows the atomic nuclei of hydrogen, carbon, and oxygen (the elements that make up cellulose). The more electrons that cluster around the nucleus, the more protons it will contain. With its positive charge, the nucleus can always sustain a negative charge environment of equal value.



THE THREE FUNDAMENTAL PARTICLES IN CHEMISTRY—The proton **p**, neutron **n**, and electron **e** are the three particles whose properties and ability to form atoms determine the laws of chemistry.



PART 6

- 110 The Essence of Geometry
- 113 Combinations and Probabilities
- 117 Positive and Negative Numbers

MATHEMATICS | an unfettered creation of the mind

Mathematics is unlike other sciences. It is often likened to the arts—and for good reason: mathematics is an unfettered creation of the mind, controlled only by the limitations of the mind itself. This is an abstract concept; yet for all the abstractions of mathematics, it is useful and necessary. To some, mathematics means little more than checkbooks and income tax. To the scientist it is a key to the understanding of natural phenomena. To the technologist it is a tool with which this understanding may be utilized. In short, mathematics is one of the bases of the modern world.

Mathematics is also the science of quantity. Pure mathematics is the science in an abstract sense. Applied mathematics is the opposite—"impure" only in that the abstractions are applied to concrete information. The science of quantity is another name for the ways of counting; and counting, indeed, is the essence of mathematics.

Mathematics developed primarily in highly advanced urban civilizations: Babylonia, Egypt, Greece, and Rome. These were the cultures in which a science of quantity was most needed. Among the earliest works in mathematics were those of the Babylonians, whose numerical, algebraic, and geometric techniques are known to have existed as early as about 1700 B.C. Probably by the third century B.C. the Babylonian number system with its idea of place-value of numbers was in use. Place-value of numbers distinguishes between the value of numbers with similar digits—between, for example, 5,050 and 5,005; it is the place, or position, of each digit relative to the complete number that determines the value of that number. Although the basis of the Babylonian number system was 60, rather than our basis of 10, their idea of place-value was sound; we still use it today. (Vestiges of Babylonian counting style are seen in the divisions of hours into 60 minutes, minutes into 60 seconds, and circles into 360 degrees). To the Babylonians we are also indebted

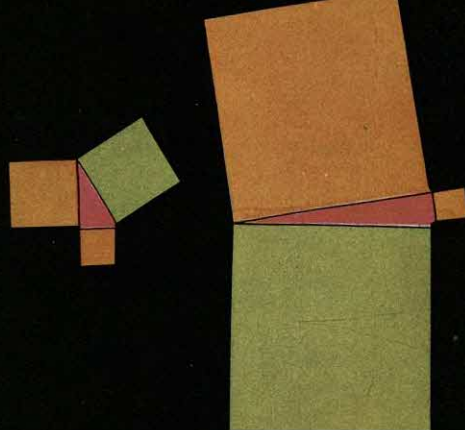
for the "invention" of the zero—without which the notion of place-value would lose its simplicity.

Egyptian mathematics can also be traced back to about 1700 B.C., at which time it included addition, subtraction, multiplication, and division—although the methods used were far more complicated than those we use today. The Egyptians also developed techniques of measurement, such as the areas of circles and triangles, and the volumes of certain solids.

It is not known with any accuracy the extent to which Babylonian and Egyptian mathematics was carried by trade or other social intercourse to Greece, but Babylonian numerical techniques appear in some Greek mathematical discourses. The Greeks were hampered in numerical processes by a cumbersome number system that lacked both place-value and zero. But Greek mathematics, thought to have begun in the fifth century B.C., made important contributions to various theoretical foundations as the Greek philosophers sought to explain natural phenomena.

These, then, were the diverse beginnings of mathematics. Literally there is no end. Mathematics continues to expand to fill the needs of the modern world. As the needs grow in complexity so must the mathematics that serves them. There is little similarity between, for example, the mathematics used by the ancient Egyptian farmer to reclaim his field from the receding Nile and that used to describe the energy levels in the atom. Modern mathematics also differs from its ancient counterpart in that it is no longer considered to consist of several disjointed parts; mathematicians now recognize the common root of all mathematics. Terms such as algebra, geometry, and trigonometry, however, are still convenient to use when one first studies mathematics.

In this volume three articles explain the bases of geometry, numbers above and below zero, and combinations and probabilities.



THE ESSENCE OF GEOMETRY | the logic of figures

Geometry was born in ancient Egypt, where the development of agriculture created a need to measure the surface area of fields. Although the name of this branch of mathematics was coined later by the Greeks, the meaning of the word "geometry" reflects its Egyptian origin, for in Greek the word geometry means "measurement of the Earth." Thus, geometry was first a science that enabled a person to determine whether the area of a triangular field was equal to, greater than, or less than that of another field having a different shape.

When the Greeks took up the study of geometry, they made outstanding theoretical contributions to it. As a result of these contributions, geometry changed from a practical instrument to a universal science that revealed the properties of

figures, even when those figures no longer stood for anything that really existed.

The transformation of geometry from a practical to a theoretical science was primarily the work of the ancient Greek philosopher Thales, who went to Egypt to study the knowledge Egyptian scholars had accumulated and who then returned to Greece to carry forward the work of the Egyptians. Thales' work was not entirely theoretical, however; since all geometric figures—circles, squares, cubes, cylinders, and so forth—are merely abstractions of real images, Thales and his successors also found practical applications for geometry.

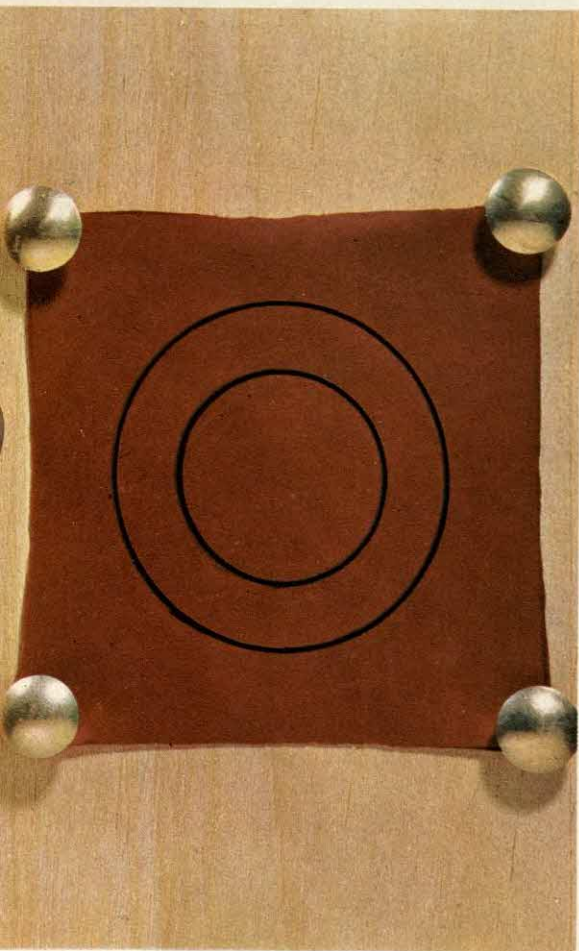
From these early beginnings, geometry made great progress through the centuries, one discovery following another. Perhaps the most important step forward

was the realization that geometry deals with abstractions of real images rather than with real images themselves.

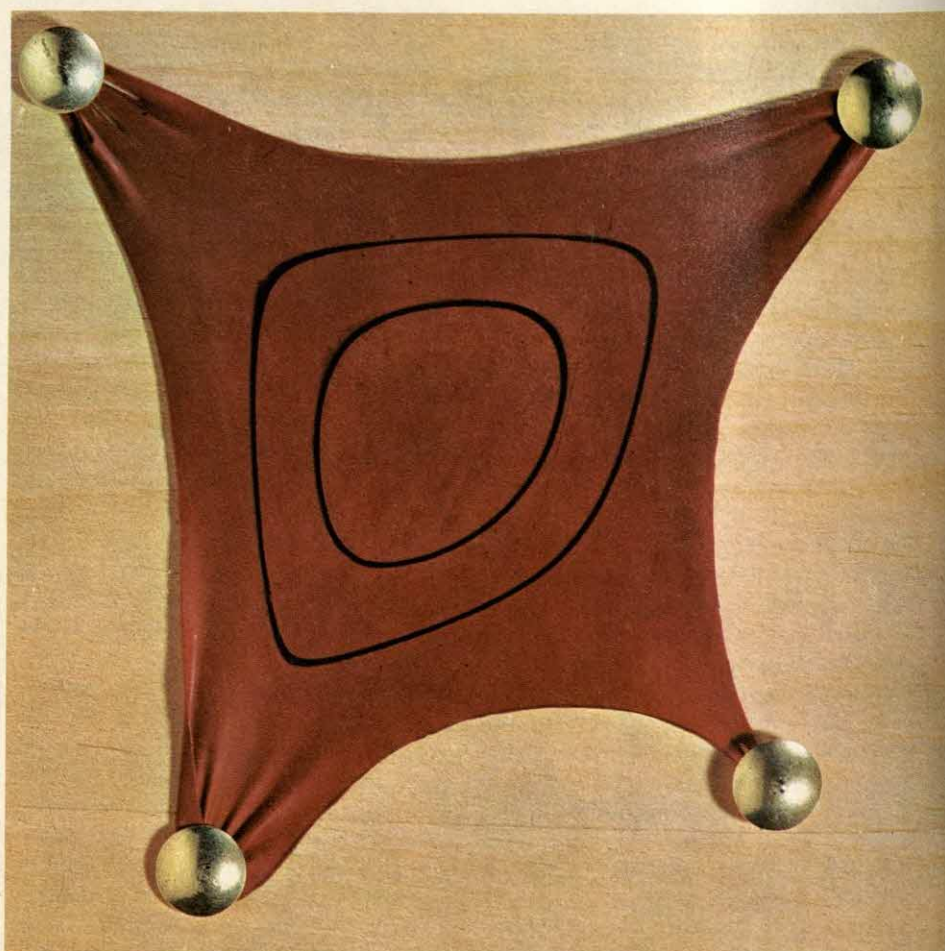
POWERS AND LIMITS OF GEOMETRY

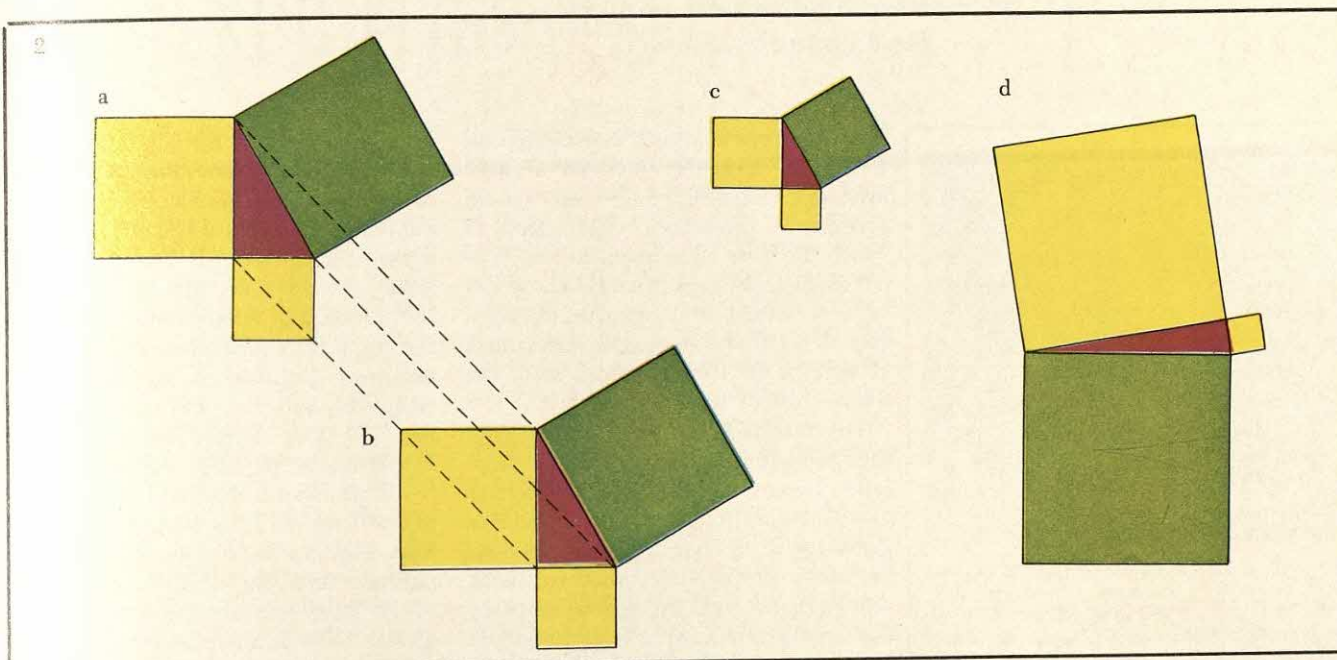
In geometry, a precise definition exists for each concept—whether it is a point, a line, a square, a circle, or a sphere. The definitions may at times seem abstruse, but the abstractions seem to have a close similarity to real objects. The straight line resembles the corner of a body shaped like a parallelepiped, the circle resembles a disk, and the sphere resembles a body like the sun or the moon. Such comparisons are useful for making geometry less abstract, but they risk weakening the argument and may lead

1a



1b





THE PYTHAGOREAN THEOREM — A well-known theorem of elementary geometry states that the area of the square of the hypotenuse (green) of a right triangle is equal to the sum

of the areas of the squares of the other two sides (yellow). This is the Pythagorean theorem, which is valid for any given right triangle (Illustration 2a), for all triangles identical to it

and obtained by simple transformation (Illustration 2b), and for any other triangle, provided it is a right triangle (Illustrations 2c and 2d).

to gross errors. Furthermore, to stop reasoning according to precise definitions usually results in contradiction.

Given an initial set of propositions and the rules of argument, which are based on the principles of logic, geometry allows the deduction of facts that are true only for the entities that have been defined and used as the starting point for the argument. While this fact may seem a limitation, it is precisely the characteristic that gives geometrical reasoning its power.

PROPERTIES OF FIGURES

Geometric figures are made up of points and have many kinds of properties; the classification of these properties leads to the division of geometry into various subdivisions. The significance of the first of these subdivisions, elementary geometry, can be illustrated by a well-known geometric property of right triangles: the square of the hypotenuse of a right triangle is equal to the sum of the squares of the two sides. (This is the famous theorem attributed to the Greek mathematician Pythagoras.)

Illustration 2a shows the Pythagorean theorem. The square constructed on the

hypotenuse is green and the squares on the two sides are yellow. The green area is equal to the sum of the two yellow areas. Once the theorem has been demonstrated for one particular right triangle, the property is also valid for:

1. All triangles identical to the one used for the demonstration, whether they lie in another plane (Illustration 2b) and however they are arranged.
2. Any other right triangle (Illustration 2c and 2d).

In elementary Euclidean geometry, a theorem is not always valid for such a vast range of figures as those obtainable from a given figure by the general transformations used above. For example, one could ask which hexagons have the property that the apothem (the perpendicular dropped from the center of the polygon to the center of one side) is as long as a side multiplied by half the square root of 3. (This property is expressed by the formula $a = l\sqrt{3}/2$.) The answer is that the property is true for all regular hexagons and, therefore, for regular hexagons of all dimensions, for all regular hexagons are similar; that is, they can be obtained from one another by an enlargement or a diminution, during which the angles do not change. The same property is not

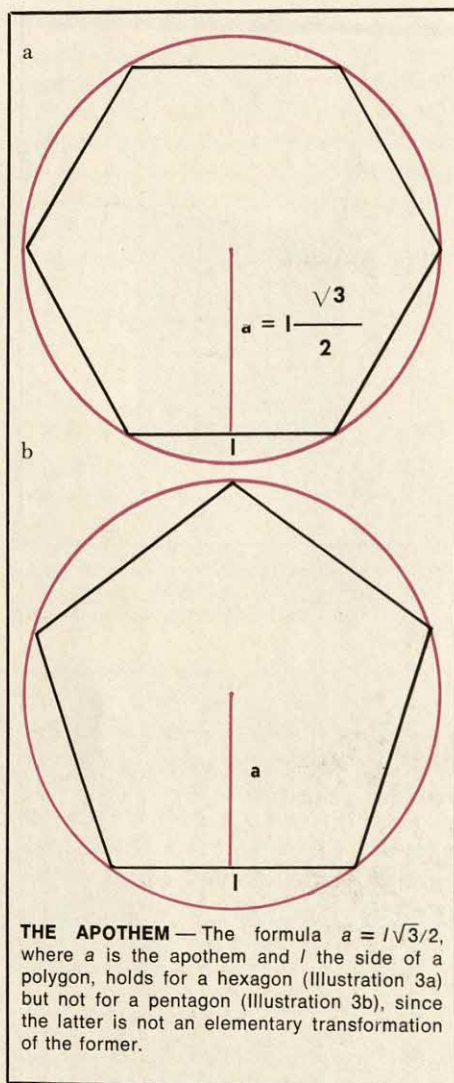
valid for a pentagon, however, because a pentagon cannot be obtained from a hexagon by means of elementary transformations. The conclusion, therefore, is that Euclidean geometry studies the properties of figures that do not vary when they are moved around on the plane or when they are enlarged or made smaller by similarity (leaving the angles unchanged). This is the most comprehensive definition of elementary geometry.

Elementary geometry is often called metric geometry because, after the transformations are made, the only properties left unchanged are the metric ones—the relations between the lengths of the various parts of the figure, between the sides and the angles, or between the angles.

A GENERAL GEOMETRY

If a triangle is drawn and then a similar, smaller triangle is drawn, the transformation is simple. Elementary geometry can be said to study the properties of figures that are not varied by an elementary transformation such as this. However, there are also properties that do not vary when more complicated transformations are carried out. For example, a cir-

3



cle and a cross might be drawn on a sunlit windowpane and their shadows on the wall or floor observed. The shadow of the circle becomes an ellipse. It has lost its essential nature because there is no longer the same relationship between outline and area in the shadow. Projection has destroyed the figure's metric properties. The same thing is true of the cross. The two straight lines still intersect, but they no longer form right angles.

If a particular plane on which the

figure is projected could be selected, as well as a particular direction of light rays, and a particular angle between the two lines, a projection would appear in which the lines were parallel. This does not conflict with what was said above, because a fundamental postulate of geometry states that two parallel lines meet at infinity. In this case, too, then, the intersection of lines is preserved.

The branch of geometry that studies such properties of figures as these—properties preserved even after the figures have been projected—is called *projective geometry*. Projective geometry permits the study of properties that are much more general than those dealt with by elementary geometry; it is an important branch of geometry because the properties that are valid in it are also valid in elementary geometry, which is actually a special type of projective geometry.

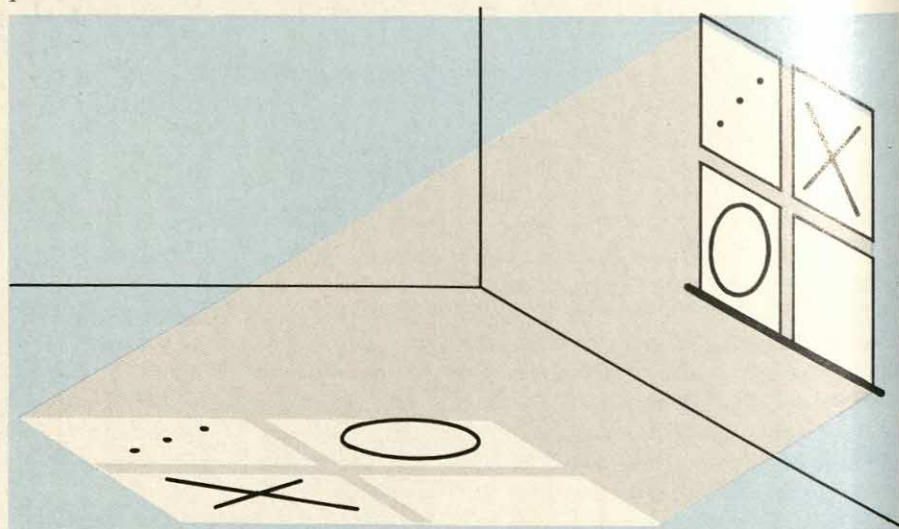
THE MOST GENERAL GEOMETRY

The most general geometry of all is topology, a little-known but extremely important branch of geometry that studies those properties of figures that

do not vary when the figures are subjected to the most brutal transformations of all—shrinkage, stretching, or twisting. Suppose a geometrical figure is drawn on a sheet of rubber: for example, a ring made of two concentric circles, as in Illustration 1a. What would happen to the ring if the rubber were stretched and deformed (without being torn) in a completely arbitrary way, as in Illustration 1b? The circles are certainly no longer concentric, and yet one property is still preserved: the figure still consists of two lines—an inner loop and an outer loop. The two lines have not intersected nor have they merged into a single line.

The study of such properties is the special function of topology; and since the properties it analyzes are also valid for projective geometry and elementary geometry, it becomes the most general and comprehensive geometry of all. Topology has applications in many fields including the design of maps, networks for electrical power distribution, guided missiles, and traffic control. Some of the properties studied by topology are only slightly intuitive, and some seem nothing less than astonishing.

4



PROJECTIVE GEOMETRY—If geometrical figures are drawn on a windowpane and projected by the sun onto the floor, the figures are transformed. The circle becomes an ellipse and the right angles of the cross become

acute angles. Alignments and intersections are preserved, however, and the curves will always be of the same family. (A circle and an ellipse can be obtained from each other; they are both conics.)

COMBINATIONS AND PROBABILITIES

three letters and three numbers yield over
17 million license plates

How many automobiles can be licensed using three letters of the alphabet and three digits? How many different ways can people sit around a table? Taking a sample of 100 transistor radios from thousands, 3 percent of which are known to be defective, what is the chance that the sample will include exactly three defective radios?

These questions can be answered through a knowledge of the laws of arrangements and combinations, which will determine the maximum number of different combinations that can be obtained from a given number of objects. This branch of mathematics is known as combinatorial analysis. Although higher applications of the theory are quite complex, a knowledge of elementary algebra and arithmetic is sufficient for an understanding of basic techniques.

THE LICENSE PLATE PROBLEM

An automobile license plate should be easy to read from a distance, even when the visibility is bad, and should be easy to remember. This last characteristic requires a small number of letters or figures, even if a large number of automobiles is in circulation. The problem is to find out how many automobiles can be numbered with the three letters and three digits, such as are used in England.

Although the point may seem unimportant, it is first necessary to define what is meant by "different license plates." The expression 415 GLL, for example, differs from 154 LGL, even though the two are made up of the same characters. Two license plates are thus different when the figures or letters forming them are different, or when the same figures and letters occupy different positions.

To determine how many different license plates of this kind can be written down, the problem must be analyzed in successive stages. First, three letters, chosen from the 26 letters of the alphabet must be arranged three in a row. Any of

the 26 letters may be used for the first letter. There are thus 26 ways of filling up this position alone. For each group of three letters with a different letter in the first position, the second letter can be written in 26 different ways. There are, therefore, 26^2 ways of writing the first and second letters. For each of the 26^2 ways of writing the first and second letter, there are 26 ways of writing the third letter. The total number of different three-letter groups that can be written is, therefore, 26^3 , or 17,576.

With three digits, however, only 10^3 , or 1,000 different combinations, can be written. The 26 is replaced by 0 through 9, or ten digits—available for each column. No number higher than 999 can be written with three digits.

The law determining the number of possible combinations of digits or letters can be worked out when the number of digits or letters available is known. Groups of numbers or symbols are defined by mathematicians as permutations or arrangements. Such groups—as those on the license plates—are called "arrangements with repetitions" in that the same group may contain the same letter or figure two or three times in succession.

The general formula for arrangements with repetition is $D_{n,k} = n^k$. The definition is exact. The disposition D of n objects in groups of k , where k is any number less than n , is given by raising the number of objects n to the power of k . The crux of the license plate problem is deciding how to arrange 26 objects in 3's. Applying the formula: $D_{26,3} = 26^3 = 17,576$.

THE SEATING PROBLEM

How many ways can six people sit around a table? The problem can be solved very simply. Suppose these six people are seated at a round table; then, taking any point between two people on the edge of the table, two arrangements can be assumed to be different if, starting

1



ARRANGEMENT WITH REPETITION—This English license plate is an example of arrangement with repetition of 26 letters and 10 numbers in groups of 3 each. With this system, license numbers can be given to 17,576,000 automobiles.

from the point and moving around the table, the people follow each other in a different order.

Suppose the first guest can choose where he wants to sit. He can choose to sit in six different places, thus creating six different arrangements. When the first guest is seated, the second prepares to make his choice. Only five empty chairs are left. The possible choices open to the first two guests, therefore, total 6×5 . The remaining number of choices is easily predictable. The third guest has 4 choices; and finally, when only one guest is left, no choice is involved and he is limited to one chair.

In total, there were $6 \times 5 \times 4 \times 3 \times 2 \times 1$ choices: a total of 720 arrangements. The figure 720 may seem a large number, but it would have been much larger if 10, rather than 6, guests had been seated around a table in all possible ways. The same reasoning would have shown that the number of possible arrangements around the table equals the product of all the whole numbers between 1 and 10. Consequently, 10 people may sit around a table in 3,628,800 different ways.

The different arrangements of a certain



SIMPLE ARRANGEMENTS—This sequence shows how 4 people can sit around a table in 24 different ways. The number of simple permutations of a number n of objects is determined by calculating factorial n , expressed as $n!$, equal to $1 \times 2 \times 3 \times \dots$. Here, for example, $n! = 24$.



number of people around a table or, in general, of a certain number of objects in a series without repetition is represented as D_n . The number that measures this is the product of all the whole numbers from 1 to n , and is abbreviated as $n!$. The exclamation mark means that the products of all the whole numbers in succession must be multiplied out until n is reached. Therefore, $D_n = n!$. The symbol $n!$ is known as factorial n and is found in many mathematical expressions; as n increases, $n!$ increases very rapidly. Its growth in the jump from 6 to 10 has been described; 100! is a number con-

taining more than 150 digits.

SOME APPLICATIONS OF THE LAW OF COMBINATIONS

The problems already solved by means of the law of combinations were fairly simple. With methods only slightly more complex than those already described, problems of great practical interest can be solved.

Suppose a dealer has bought several thousand transistor radios, all of which are the same model. He wants to make sure that not more than 3 percent of the radios are defective. He does not have time to check on the quality of the whole shipment, but only of 100 radios. Suppose that the shipment does in fact contain exactly 3 percent defective radios. If the dealer could be sure of this he could accept it; but if he picks out only 100 radios, it does not follow that 3 of them will prove defective. He may pick out 3 defective radios, but he may also find 2, or 1, or none, or else 4, 5, 6, or more. The question is one of probability.

If the dealer wants to know the reliability of the 100 sample radios, he must know what probability there is that he will pick out 0, 1, 2, 3, 4, 5, or more de-

fective radios from the sample. The solution of this practical problem can be found through the use of probability mathematics. Since the middle of the nineteenth century, probability has gained ground as a part of physical theory.

Many problems of physics have been solved through the use of the mathematics of probability. These include the problem of determining the distribution of the molecules in a mixture of different gases. This same problem of calculation can easily be extended to that of forecasting which processes will occur spontaneously, and which will take place through an expenditure of energy.

A perfect mathematical argument can be used to establish the extreme improbability—and the practical impossibility—of the molecules of two gases mixed together separating from each other spontaneously, even if they have not reacted with each other to form a new chemical compound.

With the rise of quantum mechanics, the theory of radiation was put on a basis of probability by Max Planck. The further development of quantum physics saw probability invading atomic theory.



3
DISTRIBUTION OF TWO GASES IN A CONTAINER—How will the molecules of two gases distribute themselves? This problem of physics and chemistry can be solved by the mathematics of probability (Illustration 3).

SAMPLE PROBLEM—The percentage of defective items in a large shipment of goods can be tested by checking a sample made up, for example, of 100 items chosen at random. The reliability of the sample is determined by calculating the probability of finding the known, overall percentage of defective items in the random sample.

4



POSITIVE AND NEGATIVE NUMBERS

a need for numbers below zero

The two simplest operations involved in arithmetic are addition and subtraction. To primitive man, all numbers referred to actual physical objects—such as fingers or sheep in a flock, or apples. These numbers are *positive whole numbers*.

The study of elementary arithmetic concerns absolute whole numbers such as 1, 2, 3, 8, 9, 15, and so forth. With these numbers children are taught to carry out the operations of addition, subtraction, multiplication, and division. The emphasis is on techniques of calculation.

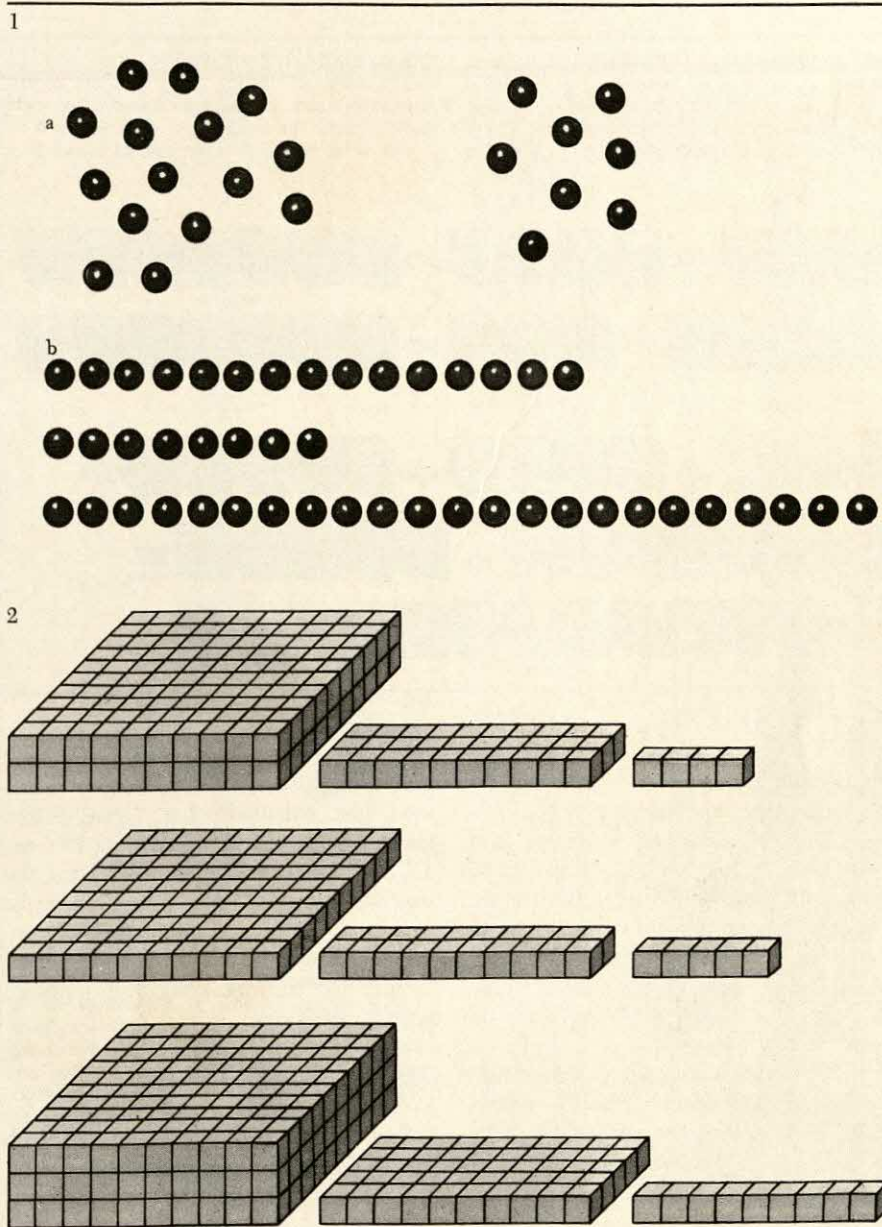
In performing arithmetical operations, people early discovered that the addition of two numbers always came out the same way no matter how the numbers were added: $3 + 12 = 15$, and $12 + 3 = 15$. In other words, $a + b = c$, and $b + a = c$. The sum, c , is not changed whether a is added to b or b to a . By virtue of this fact, addition is said to be *commutative*.

The operation of addition has still another interesting property—it is *associative*. In adding three figures, the final sum is the same whether the third is added to the sum of the first two, or the second is added to the sum of the first and third, or the first is added to the sum of the second and third. The three figures, 8, 2 and 3 may be added together in several ways: $(8 + 2) + 3 = 13$; $(8 + 3) + 2 = 13$; $(2 + 3) + 8 = 13$.

Subtraction, however, is neither commutative nor associative. The fact that a number a can be subtracted from another number b , leaving the difference, c , does not mean that b can be subtracted from a , leaving the same difference, c . Eight apples can be removed from a pile of 12 apples, but 12 cannot be taken away from a pile of 8.

The human mind, however, is able to work with numbers that do not really exist—numbers below zero, or negative numbers. Subtraction, in fact, seems to demand the negative number. With negative numbers, 12 can be subtracted from 8 by going 4 units below 0. Negative numbers are represented by a minus sign, as in -4 .

Negative whole numbers may be



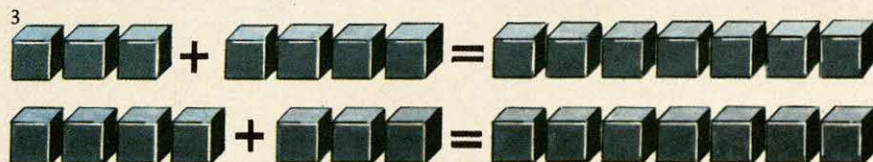
THE CONCEPT OF THE SUM—Addition is as easy an operation as its concept is subtle. A person starts from the intuitive concept of unity and moves on to the concept of multiplicity by imagining a number of associated elementary units. Illustration 1a shows two different groups of balls, 8 in one group and 15 in the other. If these are put together as in Illustration 1b, the bottom row of balls shows the total number: 23.

A SUM IN THE DECIMAL SYSTEM—The illustration is a graphic representation of the proc-

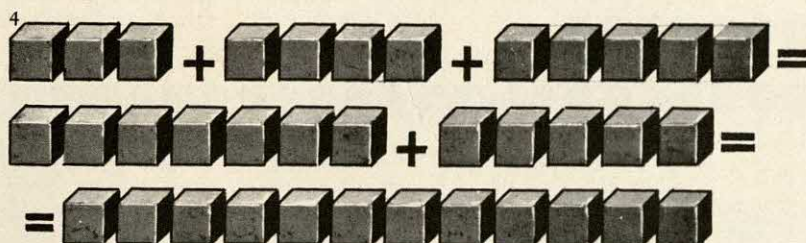
ess of addition in the decimal system. The numbers to be added are 234 and 125. To understand the operation, the significance of the various positions occupied by the digits making up the numbers must be considered. The last digits in each, 4 and 5, indicate units; the second digits, 3 and 2, indicate tens; and the first digits, 2 and 1, show hundreds. The figures in each category must be added to each other.

The sums in each of the positions are 300, 50, and 9; which is 359.

THE COMMUTATIVE PROPERTY—Adding a number b to another number a is the same as adding the number a to the number b . The illustration 3 shows that the operation $3 + 4$ and, inversely, the operation $4 + 3$ give the same result.



THE ASSOCIATIVE PROPERTY—The result of a sum does not change if two or more of the quantities being added are replaced by their partial sums. In Illustration 4, $3 + 4 + 5 = 7 + 5 = 12$, where 7 is the sum of 3 and 4.



thought of as an extension of absolute whole numbers, so that all possible subtractions of absolute whole numbers can be made. The operation of subtraction has made this extension necessary.

As a group, the absolute whole numbers, both positive and negative, require precautions that depend on how the calculations are carried out. For example, simple rules determine the absolute value and sign of a subtraction, even when the result is negative.

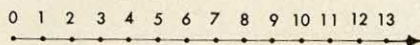
If the problem is to subtract a number from a second number that is smaller than the first, the absolute difference between them is obtained by subtracting the smaller from the greater. The result of this type of calculation is a negative number. If 23 is subtracted from 17, for example, the result is -6 . The absolute difference is 6, and the order of the terms gives the minus sign.

A special problem arises with mechanical or electronic calculating machines. In the simpler forms of devices carrying out a subtraction, if the result is negative it does not appear in an easily understandable form. For example, a mechani-

cal calculator with a 12-digit output tape, programmed to subtract 23 from 17, will give the result as +999999999994. In this case, the calculator has "gone below zero," by not simply subtracting 23 from 17, but 23 from 1000000000017. Thus, the machine avoids representing negative numbers. In the more sophisticated computers, the 9's preceding the result of the subtraction are removed and replaced with a minus sign.

THE NUMBER LINE

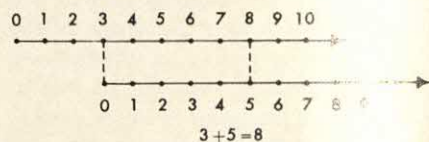
A "picture of numbers" can be made with a number line:



It is a line on which equal divisions have been marked; these divisions are labeled from 0, the starting point at the left, with numbers in the order in which they are used in counting. These positive numbers, incidentally, are sometimes called counting numbers, or natural numbers. Some mathematicians refer to 0 as a natural number as well.

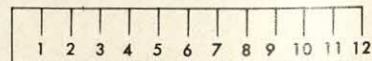
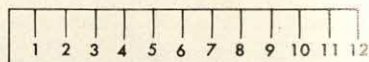
A starting point for the number line has been established, but where does this line end? This is the same as wondering if there is a last number that can be used in counting. The line never ends because there is no last number. It does not matter how large a number can be imagined; there is always one number larger. There is an infinite number of numbers. In the same way, there is no end to the number line; it extends infinitely in length.

Two number lines together may be used for addition. For example, the sum $3 + 5$ can be easily found in the following manner. The beginning point 0 of one number line is positioned directly below the 3 on the second number line:



On the first number line, the lower one, find the 5. Directly above on the other line is the 8, which is the sum of 3 and 5.

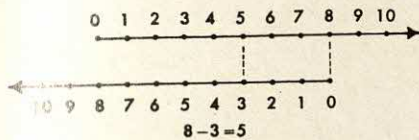
Sums up to 12 can be found in a similar way using ordinary 12-inch rulers, which may be regarded as "limited" number lines.



Not only does the sum $3 + 5$ show as clearly with the two rulers as with the two number lines above, but one can also see the sums $3 + 1$, $3 + 2$, $3 + 3$, $3 + 4$, and so forth on both the number lines and the rulers. Both the number lines and the rulers constitute a form of slide rule.

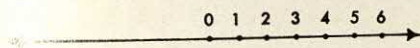
Subtraction can also be done with two number lines. To do this, one of the two number lines must be reversed, or run backwards. The numerals must appear on the number line starting at the right,

that is with zero on the right, with the numbers continuing to the left. To subtract 3 from 8, for example, position the 0 of the reversed number line directly below the 8 on the second, or ordinary, number line:

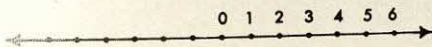


Then read the difference on the first, the upper, line directly above the 3 on the lower line. This is similar to counting backwards; the difference $8 - 3$ can be found by counting three numbers back from 8, or 7, 6, 5.

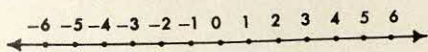
So far, the number line has been shown only with positive numbers. Negative numbers can be shown as well. The number line starting with zero and showing positive numbers to the right can be extended to the left:



New units are marked off going to the left, equal in length to those already marked off to the right:



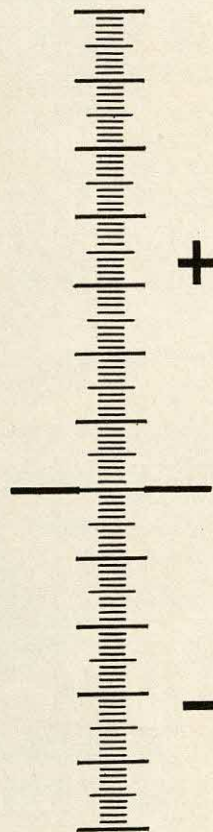
The numerals that go in the opposite direction, however, must be marked in some way to distinguish them from those to the right. It is logical to assume that since those numerals to the right are positive, those numerals to the left be regarded as opposite, or negative, and be marked with $-$ signs:



Thus the number line shows negative numbers marked $-$, and positive numbers without any sign. By convention, positive numbers do not carry any sign, although they could be so marked; 3 is regarded as the same as $+3$.

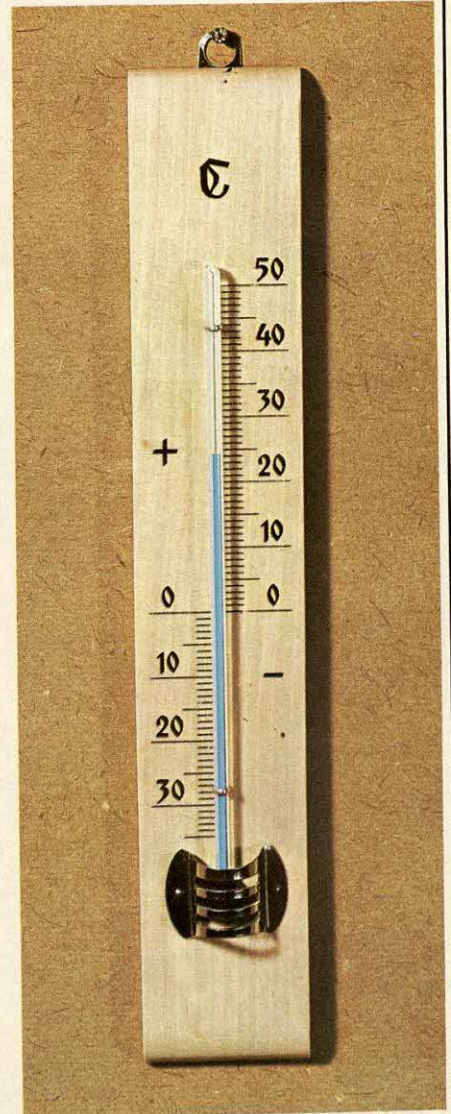
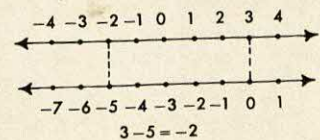
Whole numbers, that is, numbers that

5



THE THERMOMETER—The scale of a thermometer is divided into sections, each of which represents a unit of temperature, a degree. In practice, the degrees of a Centigrade thermometer are counted from the freezing point of water. Higher temperatures are counted in degrees above the freezing point. Temperatures below this reference point are identified by a minus sign ($-$); the plus sign ($+$) is sometimes used with numbers above the reference point. The thermometer is a practical example of a number line.

subtraction $3 - 5$ can be seen. Moving "backward" 5 units from 3 gives the answer: -2 .





PHYSICS | a science of structure and interaction

Since the end of the 19th century, a profound revolution has taken place in physics. This expanding field, which is concerned with the basic structure of nature and the fundamental interactions of its parts, has followed a tortuous path through the centuries in its search for answers to these problems. For much of this time, large-scale phenomena have been the center of attention, and various subdivisions have emerged that deal with specific areas—such as mechanics (dealing with objects in motion), optics, sound, and heat. The discoveries of electrons, x-rays, protons, and other subatomic particles, together with the rapid development of atomic and nuclear theories, have led to a much deeper understanding of the composition of matter and the interactions of its parts.

The ancient Greeks began the first systematic study of physics, but they tried to uncover the secrets of the physical universe before they knew the simple facts about it. When man began to progress in the field of physics, it was by attacking specific problems and letting great generalizations wait until enough theories had been tested and proved. Aristotle's *Physics*, written in the fourth century B.C., was the authority for centuries. The validity of many Aristotelian principles is established; but he, himself was confident that his conclusions would be broadened or corrected in time. Nevertheless, he was considered the final authority on all questions about the natural world during the Middle Ages. One of his erroneous beliefs was that bodies of greater weight fall through equal distances in less time than do lighter bodies. It was about 1,000 years later that the Italian astronomer, mathematician, and physicist Galileo Galilei proved him wrong.

Galileo opened a new world of physics, and he laid the foundation for modern mechanics. Earlier scientists—notably

Roger Bacon—had insisted on careful observation and experiment as the way to learn, but Galileo devised the critical experiments that set the scientific method on a firm footing. He was also the first to observe that mathematics and physics were about to join forces.

In 1642, the year that Galileo died, Isaac Newton was born in England and later became one of the greatest scientists of all time. Newton discovered many basic laws of mechanics, developed a special mathematics for problems in mechanics, and devised methods for measuring mechanical forces. Scientific reasoning based upon his principles proved to be adequate for explaining all motions and mechanical effects known to science for two centuries after his time. In the twentieth century, Newtonian mechanics is known as “classical physics.”

Besides probing nature at a more fundamental level than ever before, the twentieth century blossoming of physics has helped to coordinate and substantially unify its previously disjointed areas. The continued study of the properties of atoms, individually or in large numbers, and of their nuclear constituents is the main preoccupation of physicists today.

In common with all the sciences, physics is based on two pillars: observation and experimentation. To investigate a particular phenomenon, it is necessary to make a careful and critical examination. This often calls for additional experimentation—detailed examination of the phenomenon under prearranged, controlled conditions. In this way, a physicist can usually find out a great deal more about the phenomenon. The “experimental method” has undoubtedly played an invaluable part in the advancement of science.

Another important aspect of physics is the interpretation of experimental findings in terms of general concepts and

specific models. At all times, it is necessary to be precise about meaning; here, the language of mathematics is indispensable. The main endeavor of physicists who are interested in this approach is to obtain the rules of the game in a well-defined mathematical form. Predictions can then be made, and these in turn can be tested experimentally, with the outcome indicating whether the theory is correct or in need of modification.

Because physics purports to deal with the basic laws of nature, it necessarily cuts across the frontiers of all sciences. The chemist and the physicist are one when describing the formation of molecules or molecular transformations in chemical reactions. The astronomer's description of a spiral galaxy collapsing in its gravitational field, or of a bright star burning up, is in terms of the same laws as derived by physicists for other situations. The seismologist and oceanographer deal with waves and their properties, while in archaeology and paleontology, radioactive dating is a commonly used technique. Today, physics is increasingly applied to the life sciences, and this area holds great promise for the future. For a greater understanding and appreciation of nature in its many forms, a knowledge of physics is indispensable.

In this introductory volume—and in Volumes 14, 15, and 16—various phases of physics are examined and discussed. The articles span a great range of subjects, from the large scale of an automobile in motion or a pendulum swinging, to the small scale of protons and neutrons bound together within the nucleus of an atom. The three articles in this volume deal with essential concepts of today's physics; subsequent articles will illustrate the breadth and scope of this fascinating area of science—one that continues to develop and promises to be vitally important to mankind in the twentieth century.

WORK | physics in daily life

In the world of inanimate objects, certain forces exist—such as the weight of an object resting on the ground—that do not result in motion. From the point of view of physics, such objects can be studied merely by defining the conditions under which these forces attain equilibrium and remain motionless.

When motion exists, however, forces are in operation to produce or stop that motion. The result of such forces is usually called “work.” In order to measure work in numerical terms, it is necessary to define the concept of work and then to compare this definition with the commonsense concept of work. Once this is done, examples of work found in nature can be considered.

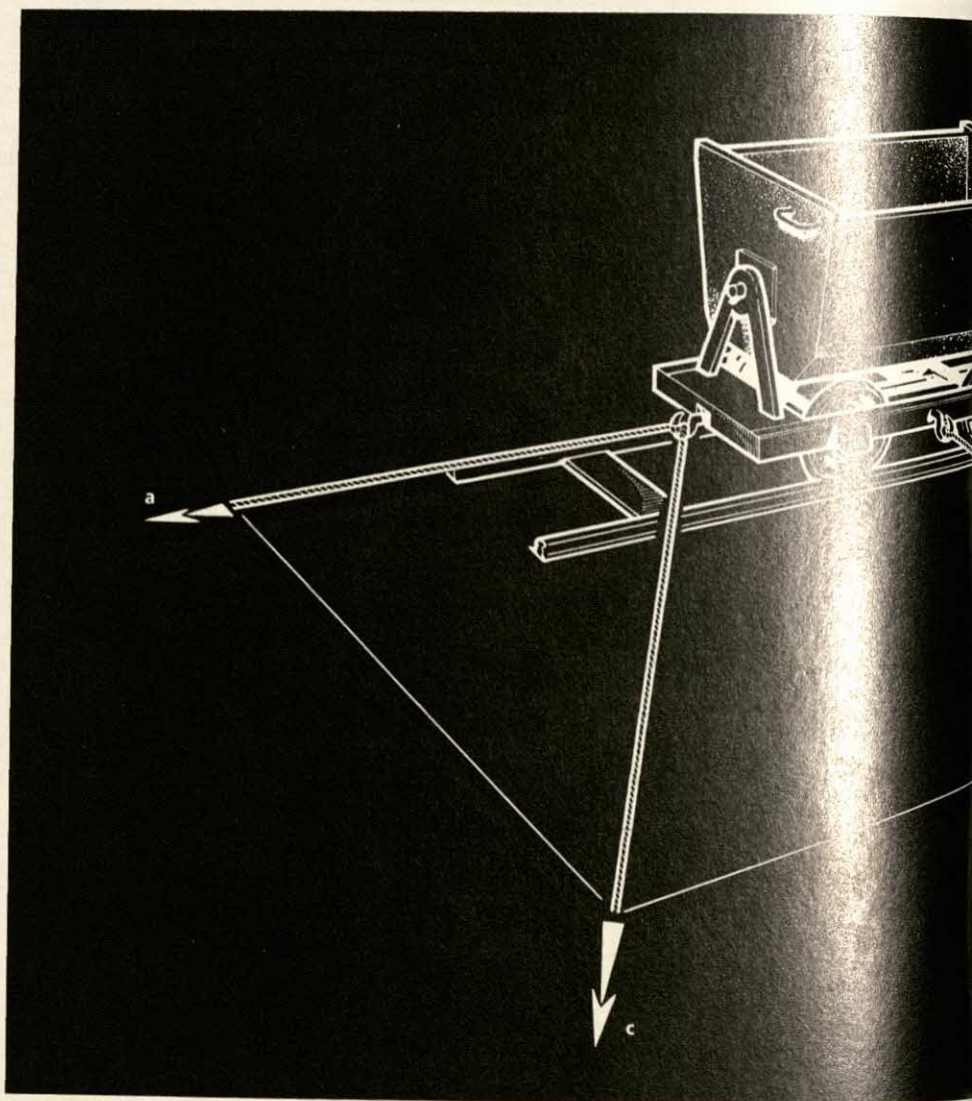
THE CONCEPT AND DEFINITION OF WORK

Work is said to be performed whenever force is applied to a resistant object and the object is moved along the line of action of the force. If someone manually pushes an automobile when the brakes are set, there will be no motion. Inasmuch as the application of force against the object (the hands against the automobile) does not move the object, no work is performed by that force. If the brakes are suddenly released, however, and if the pushing force is strong enough to overcome the resistance of friction, the automobile will move. In this case, the force can be said to perform work—enough work to overcome friction and set the vehicle in motion. The car will, in fact, move in the direction of the pushing force. Inasmuch as the object moves in the same direction as the force applied to that point, according to the definition work is performed.

THE COMMONSENSE CONCEPT OF WORK

In the example given—that of exerting force against a braked automobile—the effect of the exertion implies that work

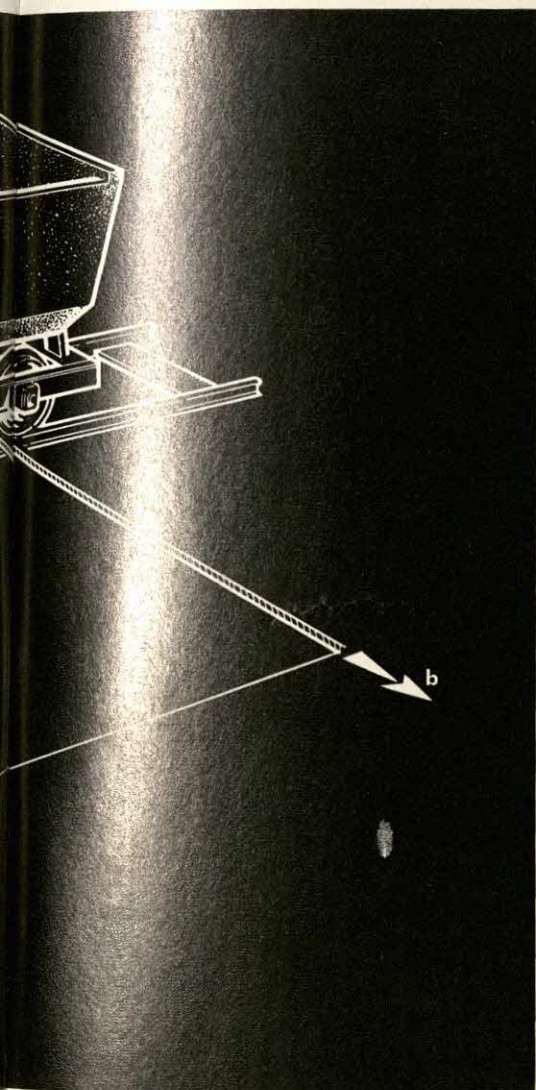
1



THE STRICT DEFINITION OF WORK—To this cart on rails is attached a rope by which the cart may be pulled. In order to set the cart in motion, it is necessary to pull the rope in the direction along which the cart can move, that is, along the rails. The force exerted on the cart is indicated by the arrow at the end of each rope, pointing in the direction in which the force is exerted; the length of the rope represents the length of movement resulting from the force exerted.

If the rope ending at arrow **a** is pulled in the direction of the rails, all the force applied to move the cart is effective, and a maximum of work is performed in proportion to the force available. If the rope ending at arrow **b** is

pulled, however, in a direction perpendicular to that of the rails, the force exercised at the point of application—where the rope is attached to the cart—cannot move the cart, because the cart can only be moved in the direction of the rails; and no work is performed. Even if the cart is, for some reason, already in motion along the rails, and the rope is pulled in a direction perpendicular to the rails, with the point of application moving along with the cart, still no work is performed, because the force exerted has no effect on the movement of the cart. Finally, if the force is exerted along the rope ending in arrow **c**, at an acute angle with the direction of the rails, some work is performed, but less than that in the



first case, when the force was exerted in the direction of the rails.

It is now possible to define work more precisely: work is the product of the amount of force exercised in setting an object in motion, in the direction of that motion, multiplied by the distance along which the object is moved.

Therefore, to calculate the amount of work performed by a given amount of force, the force itself and the direction along which the force is exerted (as by the arrows in the sketch) must be indicated, as well as the distance along which the object is moved (as by the lengths of rope); finally, the amount of the force must be multiplied by the distance of the motion of the object.

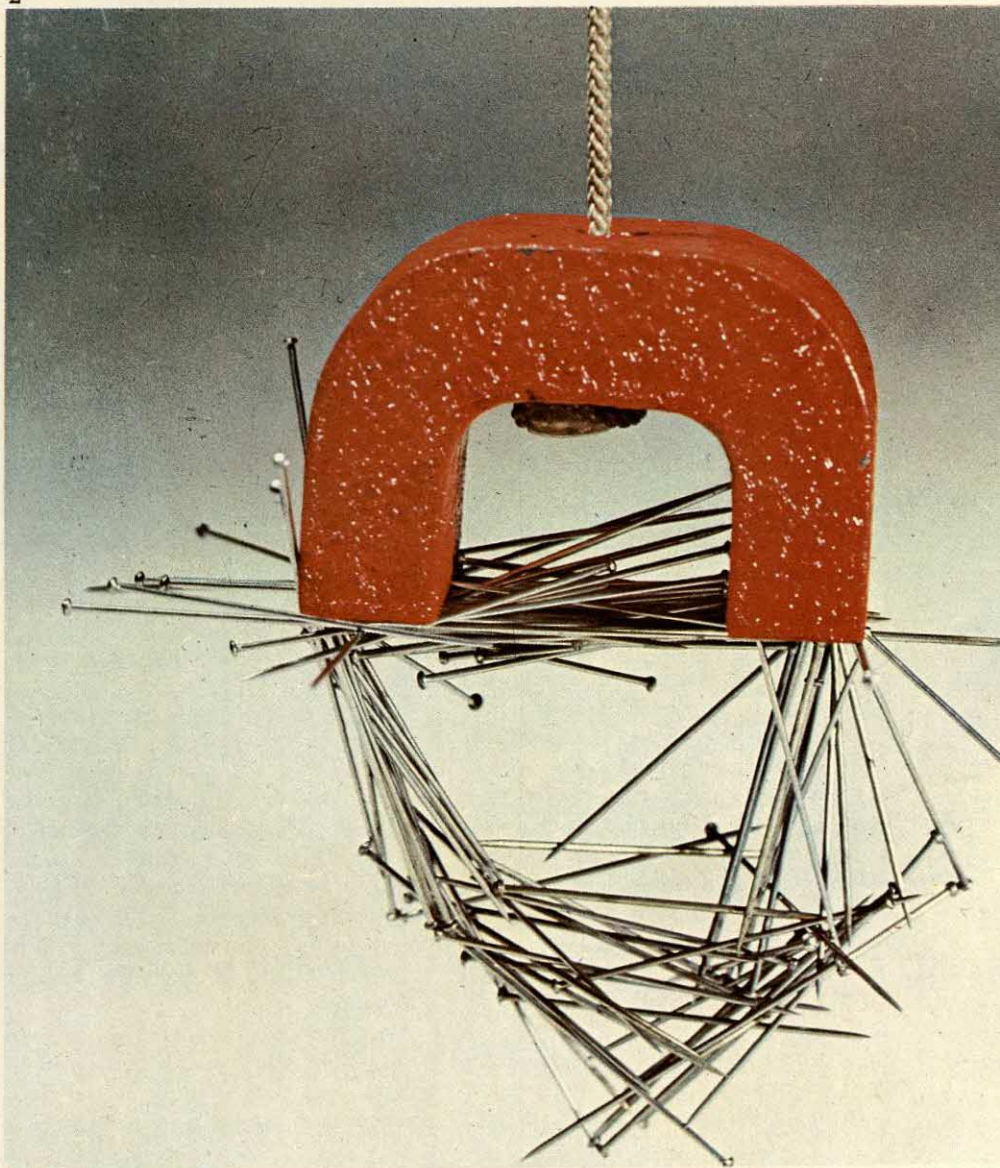
is being performed; but this is not so, according to the scientific definition of work. This discrepancy must be clarified to avoid confusion between the common-sense and scientific definitions of work.

When the arms or legs exert force, the muscles are in a state of tension that consumes energy and, after a period of time, causes a sense of fatigue. It can be demonstrated, however, that if identical force

OPPOSING FORCES AT WORK—The field of force surrounding the magnet performs work on the pins, attracting them upward against the downward pull of the field of force of the

Earth's gravity. Thus, forces of different kinds can act on the same object, and one force can cancel out the work done by another force. A compass illustrates magnetism at work.

2



3a



THE MEASUREMENT OF WORK—Inasmuch as work is defined as the product of force by distance of motion, the unit for measuring work would be the product of the respective units for measuring force and length. For example, a force of 1 dyne (roughly equal to the weight of 1 milligram, or mg) that displaces an object at its point of application through a distance of 1 centimeter (cm) performs 1 erg of work. Thus, an ant raising a crumb weighing about 1 mg for a distance of 1 cm performs 1 erg of work. A force of 1 newton (roughly

equal to the weight of 0.1 kg) that displaces an object at its point of application by 1 meter (m) performs 1 joule (j) of work (about 0.1 kilogram-meter, or kg-m, or about 0.738 foot-pound, or ft-lb). This is about the amount of work performed by lifting a cup of coffee from the table to the lips.

A force of 1 kg that displaces an object at its point of application by 1 m performs 1 kg-m of work (about 7 ft-lb). This is the amount of work performed by lifting a book weighing 1 kg (about 2.2 lb) from the floor and placing it

3b



on a table 1 m (about 39 in.) high.

These are all measurements of rather small quantities of work. A much larger unit, that of the kilowatt-hour (kw-hr), which is the equivalent of about 370,000 kg-m or 3,700,000 j. It is the work performed by lifting 370,000 kg (about 360 tons) by 1 m, or 36 tons by 10 m. It would require several days of human labor to accomplish this and would cost hundreds of dollars, but if an electric motor or a crane is used, the same work is performed quickly and inexpensively.

is exerted against a vehicle that is not movable and one that is movable, different degrees of fatigue will result; the fatigue will be greater if the vehicle has actually been moved and a quantity of work has been performed. If the vehicle has not been moved, the muscles have been fatigued only because of their state of tension; but if the vehicle has been moved, additional energy, needed to set the vehicle in motion and to overcome friction, has also been consumed.

WORK IN FIELDS OF FORCE

In order to understand the concept of work, an example has been presented of a force as obvious as that of manual

exertion. But work can be performed through the action of forces of quite another sort.

If an object is dropped, for example, it is really pulled down by the force of gravity. This force performs work that can be measured by multiplying the weight of the object by the distance of the fall. This is an example of a force acting on an object although no material medium exists between the force and the object. In this case, the object is said to be within a field of force—the field of gravitational force.

Many other examples exist of magnetic fields within which work is performed on objects. One such example would be a piece of iron moved by the force of a

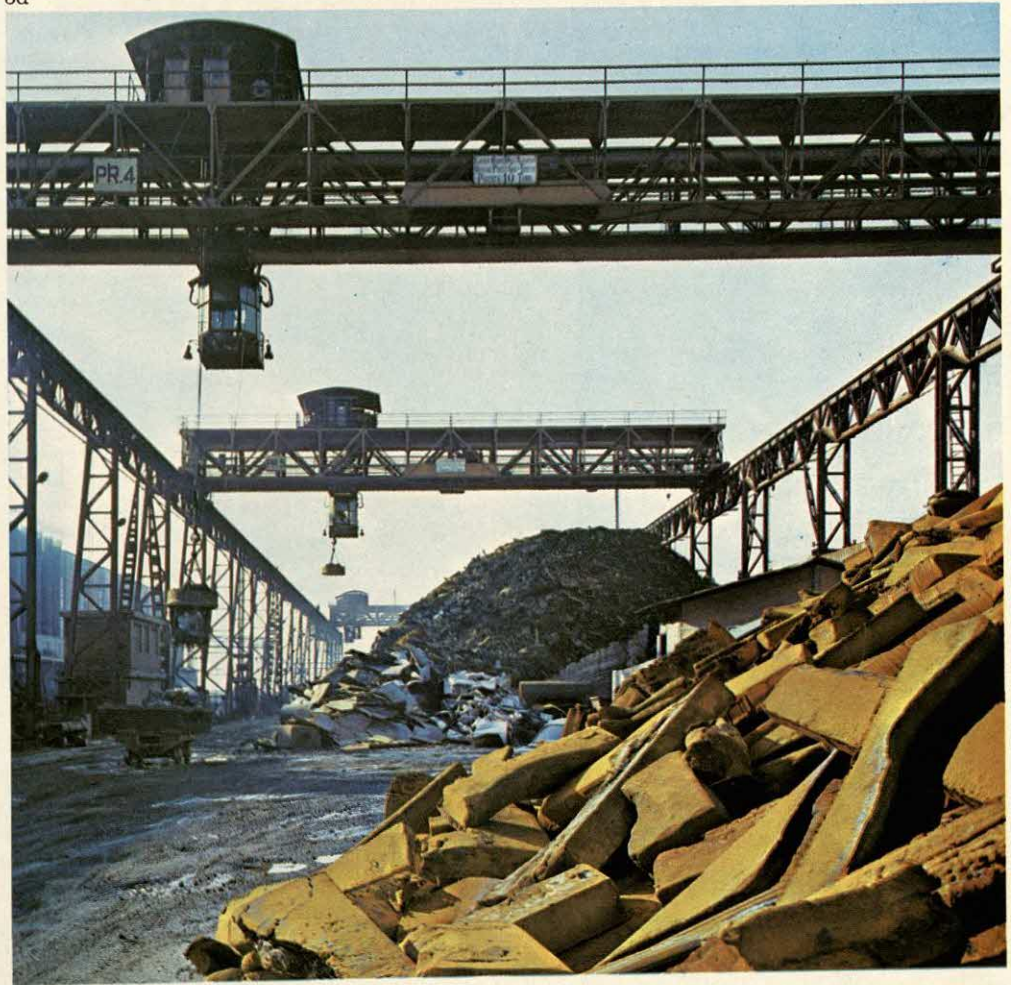
magnet within the magnet's field of force.

Various sorts of force can act simultaneously on an object. If an electrically charged piece of iron is dropped, for example, it is subject to work resulting both from the gravitational field of the Earth's magnetism and possibly from an electrostatic field produced by other charged objects close to its own trajectory.

POSITIVE AND NEGATIVE WORK

If a sledge is pulled along a road, a certain amount of energy is needed to overcome the friction caused by the contact of the sledge with the ground. What is friction? Insofar as the concept of work

3d



3c



is concerned, friction is a force in opposition to the force being imparted to the sledge, applied at the point of contact between the sledge and the ground. It might be said that the force of friction performs work, but in this case the work is negative because its effect has been against the motion of the sledge.

If an object is raised from the ground to the roof of a building, positive work is performed. If the object is lowered (and not merely dropped) to the ground, however, force must be applied to it during the descent, and this force must be applied in an upward direction, directly against the direction of motion of the object—resulting in negative work. The sum of the positive work performed in

raising the object and the negative work performed in lowering it is zero, and therefore no work at all has been performed on the object between the time of its being raised and its return to the original point on the ground.

THE IMPORTANCE OF MEASURING WORK

The concept of work has many applications in engineering. In order to estimate the power of a crane's engine, or to evaluate the size of an engine needed for a given vehicle—or the expense and techniques required to hoist construction materials, the amount of work required to accomplish the task must be known.

In science, any force that performs work is calculated by measuring the work performed. The amount of work required to form a mountain, for example, is measured by multiplying the weight of the mountain by its height. Who or what supplied the energy needed to perform this work? This question is meaningless unless one first knows the amount of work for which the cause is sought.

Thus, by observing a star that is increasing in volume, it is possible to calculate the amount of work performed by the force that is raising its outer crust. The value obtained by such a calculation is very useful in investigating the causes of the star's expansion.

ENERGY | the driving force of the universe

In the world of science, no word is more important than "energy." The laws that determine the characteristics of energy are basic to chemistry and biology, to physics, and to all other sciences. Energy is intrinsic to an apple that falls and to a lump of coal buried in the Earth for thousands of years, to a child at play, and to a huge aircraft carrier at sea.

Energy is neither tangible nor visible, but it is always recognizable. The history of man, from cave dwelling to space flight, has recorded vast and unexpected progress with the discovery of each new way to utilize a source of energy, from the kindling of fire to the splitting of an atom. Indeed, it was only by using the energy in their own bodies that men and animals have been able to survive. The study of everything in the universe that moves requires an understanding of the nature of energy.

THE ASPECTS OF ENERGY

Energy has numerous forms. Of these, the most obvious is mechanical energy. The sight of a spectacular waterfall evokes a sense of wonder at the amount of energy released by the falling of such an enormous weight of water, and even a sense of danger at being too close to a place where so much energy is released.

In some mountainous locations, as a result of centuries of erosion by wind, ice, and water, a great boulder is left

precariouly balanced in such a way that the slightest disturbance would threaten its equilibrium and cause it to fall into the valley below. This, too, may evoke a sense of danger, because of the mere imminence of a release of energy, although the boulder is not in motion and no energy is apparent.

In order to understand what these two forms of energy—the waterfall and the balanced boulder—have in common, a more precise definition of energy is necessary.

WHAT IS ENERGY?

Whenever force is applied to a body in such a manner as to displace that body along the line of action of the force (that is, other than perpendicularly), work—in a scientific sense—is accomplished. This definition of work is fairly close to the commonsense definition, which also associates work with the use of force applied to an object and the displacement of the object. Examples of work are the lifting of a weight, the sawing of a tree trunk, and the throwing of an object.

In order to carry out work, energy is needed. In fact, energy can be defined as the capacity for doing work. Falling water has energy. This energy is displayed in the erosion of the rock on which the water falls and also, even more obviously, in the increased velocity of the water below the fall.

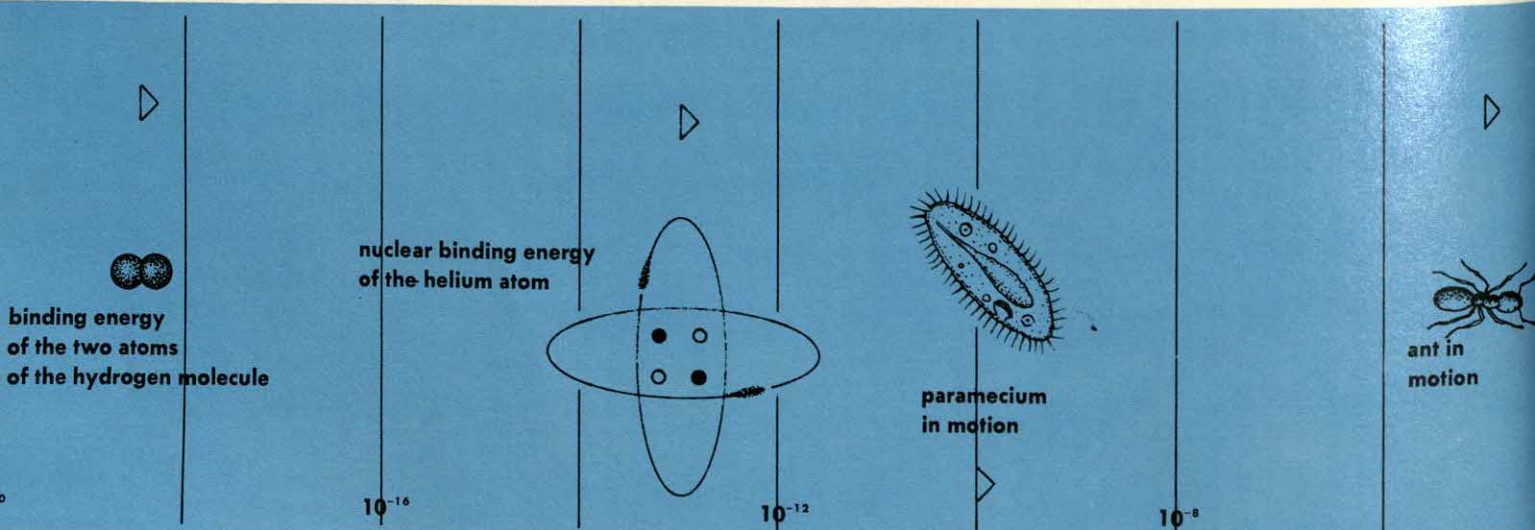
A moving projectile has energy—enough, in some cases, to pierce armor. A piece of red-hot iron has energy; if it is plunged into a vessel containing water and the vessel is tightly closed, the water will be transformed into steam. Lacking any other outlet for expansion, the steam will burst the vessel. A ray of light has energy; this energy can take the form of heat and, as in the example of the red-hot iron, can eventually be used to perform mechanical work.

Thus, various kinds of energy—such as heat or light energy—can be transformed into mechanical energy, which is the simplest form of energy and the easiest to understand.

THE MEASUREMENT OF ENERGY

Energy, as has been stated above, is the capacity for doing work; therefore, energy may be measured according to the amount of work accomplished. The units of measurement are identical for energy and work.

A useful unit for the measurement of energy is the kilogram-meter (kg-m), which is the amount of energy needed to raise 1 kilogram a distance of 1 meter. (The same amount of energy would raise 7½ lb about 1 ft, or 1 lb about 7½ ft, and would comprise 7½ foot-pounds.) Two units of energy measurement used in physics are the joule and the erg. The



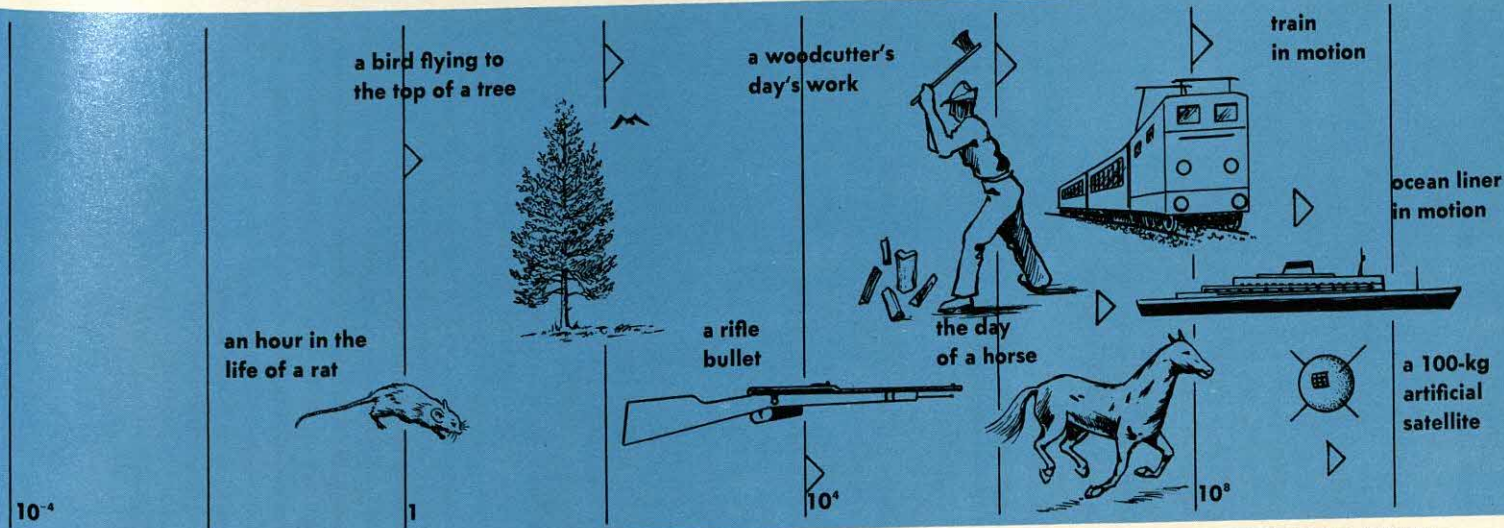
WATERFALL—A spectacular waterfall conveys a tremendous impression of power. An enormous amount of energy is released at the bottom of the cascade, causing erosion in the rock of the stream bed.

BOULDER IN EQUILIBRIUM—This formation is the result of centuries of action by wind, ice, and rain. At any moment the boulder might lose its state of equilibrium, fall, and release a considerable amount of energy.

1

2

3



ON THESE AND THE FOLLOWING PAGES ARE EXAMPLES OF ENERGY (IN KILOGRAM-METERS) THROUGHOUT THE UNIVERSE, FROM THE ATOM TO HUMAN AND FINALLY TO SOLAR ENERGY.

joule (j) is the energy equivalent of about 0.1 kg-m (or about 0.738 ft-lb), and results from the application of 1 newton of force to displace its point of application through a distance of 1 m. An erg is one ten-millionth of a joule and is the amount of energy needed to accomplish the work of 1 dyne of force to displace its point of application through a distance of 1 centimeter. Energies of the order of a few ergs, for example, are used in the small movements made by insects.

A unit commonly used to measure energy is the kilowatt-hour (kwhr), which is the equivalent of about 360,000 kg-m or 3,600,000 j. The kilowatt-hour is useful for purposes of comparison of the costs of different kinds of energy. An electric motor producing 1 kwhr of mechanical energy (the power of 1 kilowatt for 1 hour) would consume about 1 kwhr of electrical energy (actually somewhat more, because of certain energy losses that are ignored here). Due to the efficiency of modern technology, this amount of electricity costs only a few cents. The same amount of energy would be consumed by the muscles of a mountaineer carrying a pack from sea level to an altitude of about 3,600 m (about 11,800 ft).

KINETIC ENERGY AND POTENTIAL ENERGY

Examples were given above—in the case of the waterfall and the boulder—of two forms of energy, one associated with motion, the other associated with position.

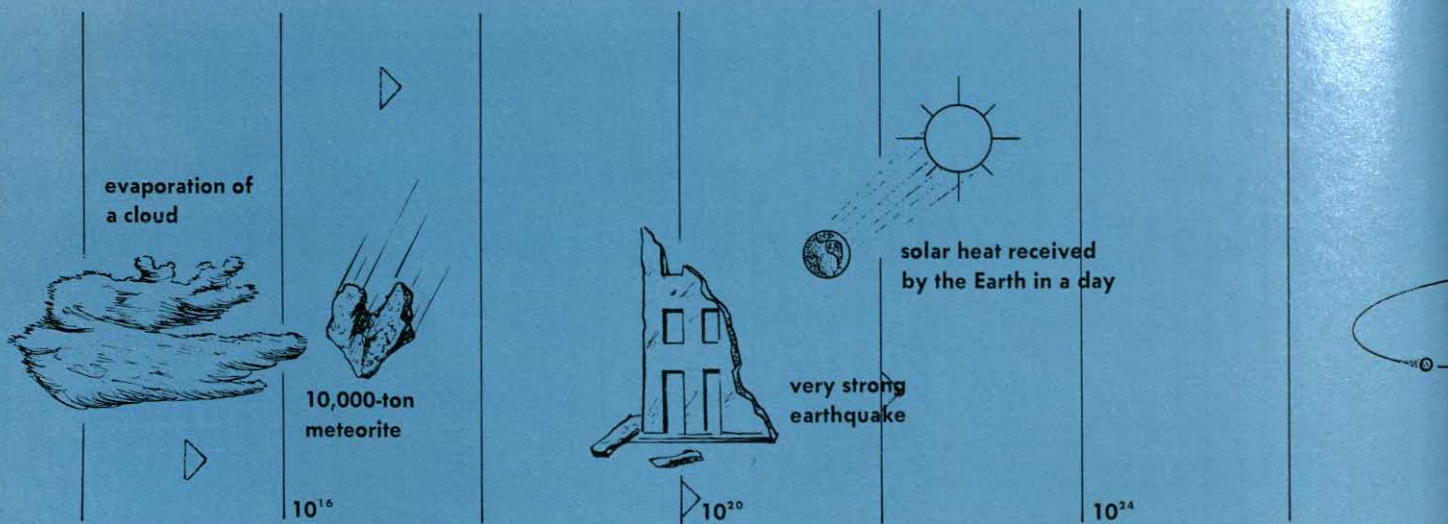
Any body in motion releases energy when it is slowed down, but this same energy was needed to impart the motion in the first place. For example, an automobile in motion, with the engine in neutral gear, will continue to move a certain distance uphill before stopping. The energy resulting from its velocity drives it up a slope that would otherwise have made it stop. In order to give the automobile the velocity needed to ascend, however, it was necessary to run the engine for a certain length of time. The engine that supplied this energy in turn derived the energy from the fuel consumed and transmitted the energy to the mass of the vehicle.

The form of energy contained in bodies because of their state of motion is known as energy of motion, or kinetic energy. A second form of energy that a body may have is potential energy. This is the form of energy that a body has because of its position. For example, if a magnet is attached to a table and a small piece of

iron is placed near it, the iron will be drawn to the magnet unless the iron is also attached or held down. If the magnet is powerful and the piece of iron is large, the contact between the iron and the magnet may be violent. The amount of energy used in making the contact depends largely on the distance of the iron from the magnet. Even a set of flowers on a windowsill has energy; if the pot falls off, this energy may have unpleasant results. Energy that depends on the position of the bodies involved is known as potential energy. In the example of the flower pot, the amount of potential energy increases in proportion to its height above the ground, and thus clearly depends on its position.

Similarly, kinetic energy depends on the properties of the body in motion and the nature of the motion itself. Two bodies of the same mass, moving at the same velocity, have an identical amount of kinetic energy. Two bodies of different mass, however, moving at the same velocity, do not have an identical amount of kinetic energy; the body with greater mass has more kinetic energy, in direct proportion to the difference in its mass. Two bodies of the same mass, moving with different velocities, also have different amounts of kinetic energy. If one

4



body moving with twice the velocity of the other, for example, the faster body has four times as much kinetic energy as the slower body. Kinetic energy does not increase in direct proportion to the increase in velocity, but in proportion to the square of the velocity.

THE CONSERVATION OF ENERGY

Thus, a body may have energy either because of its position (potential energy) or because of its motion (kinetic energy). Energy in either form, however, was not an initial property of that body; the energy had to be imparted at a specific time. For example, snow lying on a mountain has potential energy that it may release by descending as an avalanche. This energy was derived from the sun, which had evaporated water on the surface of the Earth; that water had risen in the form of vapor, to higher strata of the atmosphere, and had then condensed to fall as snow on the mountain. The energy of the sun was needed to change the water to vapor so that it could rise above the height of the mountain before it condensed into snow.

A bullet fired from a gun travels at a

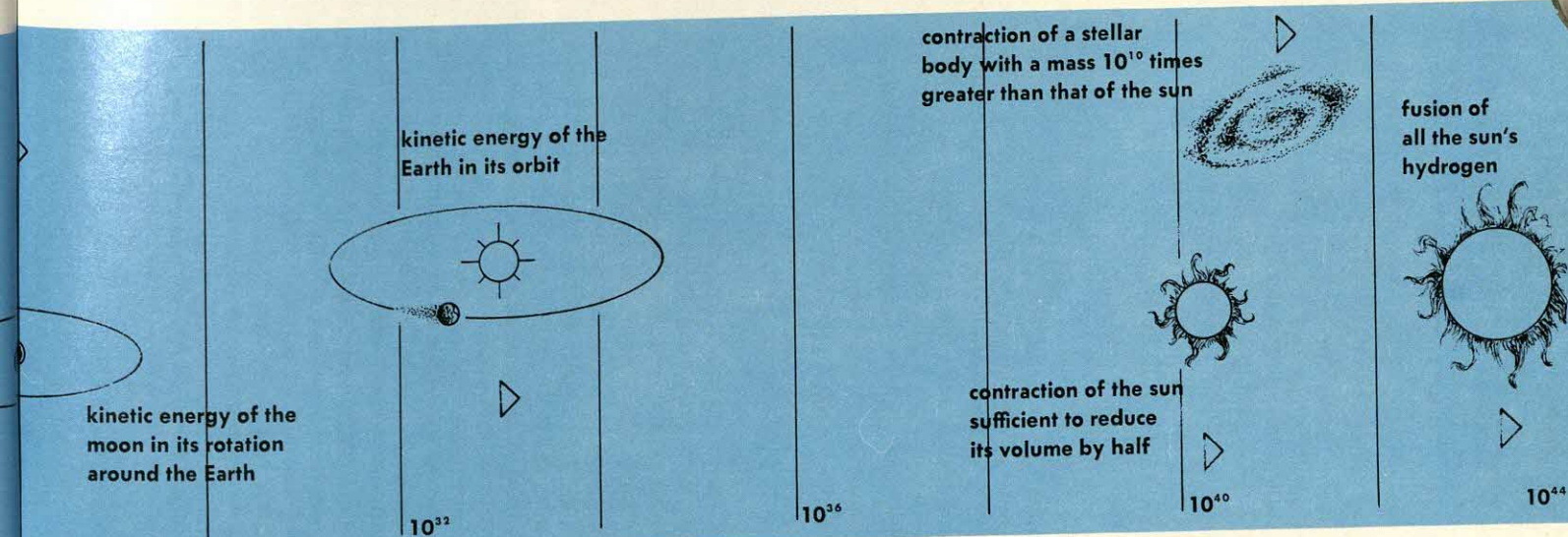
high velocity and possesses a certain amount of kinetic energy. Before it was fired, it did not possess this energy; the kinetic energy was imparted to it by the gases of the exploding gunpowder.

A single body, or a number of bodies, cannot receive energy from another source without coming in contact with other bodies or exchanging energy with other bodies. If nothing touches, brakes, heats, pushes, lights, or attracts a body, it continues to have whatever potential or kinetic energy it had originally. However, an isolated body (one that neither receives nor transmits energy in relation to other bodies) may seem to gain or lose energy. A pendulum, for example, which may be supposed to be subject to neither friction nor atmospheric resistance as it describes its arc, first rises to the right, then stops, reverses its motion, falls with increasing velocity, rises again to the left, stops once more, reverses its direction, falls again, and again rises to the right. At certain instants the pendulum is at rest and evidently has no kinetic energy; at other moments it moves swiftly and has no potential energy. What causes this variation, inasmuch as no one has touched the pendulum?

The pendulum stops when it reaches its most elevated position. It attains the

greatest velocity at its lowest point of the arc from left to right and back. When it stops, it has maximum potential and no kinetic energy; at its lowest point it has maximum kinetic and minimum potential energy. Thus, there is an alternation of kinetic and potential energies: when one is high, the other is low, and vice versa. The sum of these two forms of energy possessed by the pendulum is constant, however, and remains constant until something collides with it or slows it down by braking. As long as it remains isolated, and neither receives nor loses energy, it retains a constant amount of energy, potential and kinetic in combination.

This observation, based on the particular example of the pendulum, is a general rule of all phenomena in physics, whether they occur within a single atom or on a cosmic scale. *The energy of a system of isolated bodies never changes.* This general principle is universally valid and verifiable, even when matter disintegrates. The more general theory cannot be understood without studying at least the fundamental principles of the theory of relativity. However, in the simplified form stated above, where only potential and kinetic energies are present, the general principle is applicable.



ATOMS AND MOLECULES

a theory proved after
two thousand years

That matter consists of very small particles—atoms—and that each atom of a substance has the same properties as any larger quantity of that substance is common knowledge today. This concept of matter, first advanced two thousand years ago by the Greek philosopher Democritus, is known as the atomic theory. It was abandoned for a long time because, in the form in which Democritus had stated it, the theory did not lend itself to any experiments or contribute to the interpretation of any phenomena.

As a result of certain experiments made toward the end of the eighteenth century, chemists concluded that matter must be composed of atoms, and that Democritus' hypothesis was essential to the explanation of a large number of phenomena.

The atomic theory was advanced again in 1808 by the English chemist John Dalton, who understood its usefulness in explaining the law by which elements unite and produce compounds. It had become practical to think of matter as being made up of atoms, but scientists of that time had no knowledge of even the most elementary properties of atoms.

During the latter part of the nineteenth century, experiments led to a better understanding of atomic properties, and by the end of the century a well-defined atomic theory had been developed. Scientists then began to study the atomic structure of matter by observing those phenomena that could best be interpreted by admitting the presence of molecules, which are defined as small aggregations of atoms that manifest all the properties of a given substance. As the amount of chemical knowledge grew, however, it became increasingly clear that Dalton's theory, for all its success, had left certain important questions unanswered. It led to no conclusion about the absolute weight or size of atoms nor was it clear about relative weights of atoms. The study of gases would resolve such questions.

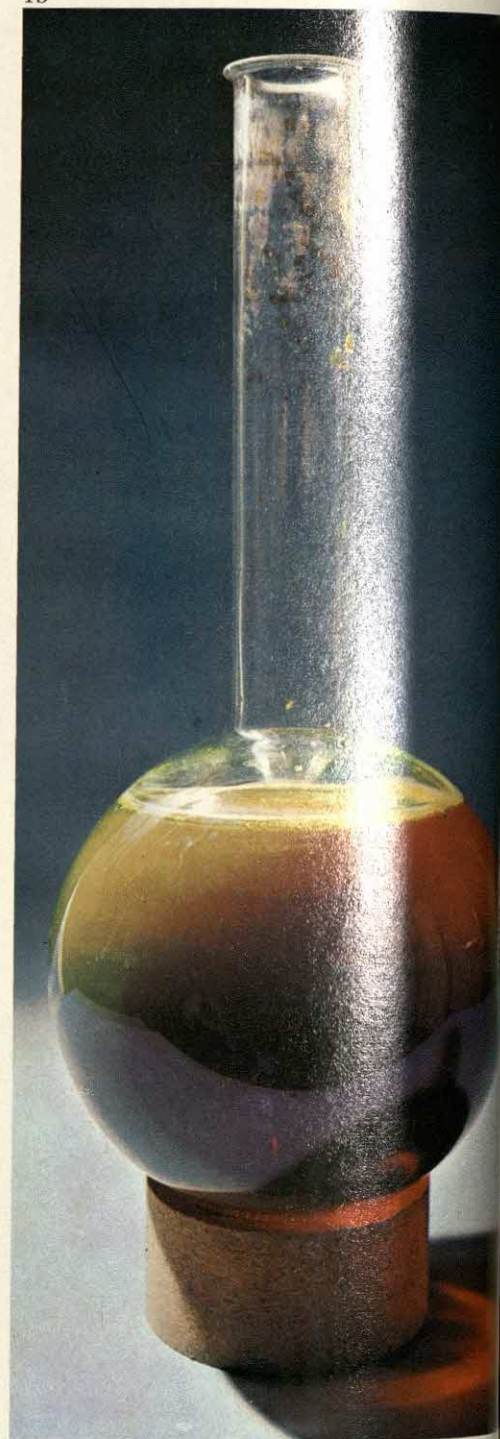
THE SUBDIVISIBILITY OF MATTER—That matter can be subdivided is easily demonstrable by tearing, cutting, or breaking it. Subdivisibility can also be demonstrated by placing a soluble substance in water. Before the substance dissolves it is a solid with given dimensions; afterward it is dispersed in the liquid to the extent of the amount of dilution that has taken place. Illustration 1a shows a gram of the dye fluorescein, a substance easily soluble in water, which remains visible even when a small amount of it is dissolved in a large amount of water. Illustration 1b shows the gram of fluorescein dissolved in a liter of water. Its presence is revealed by the intense coloring. When the solution is thoroughly mixed, the substance is uniformly distributed in the water; no areas of the solution are more dense than other areas. If a cubic centimeter of this solution is mixed in another liter of water, the new solution (Illustration 1c) will contain a thousandth of a gram of fluorescein. The fluorescein is clearly visible. Additional dilutions result in solutions containing a millionth of a gram per liter (Illustration 1d) and a thousand millionth of a gram per liter (Illustration 1e). The latter is a high degree of dilution, yet the fluorescein is still clearly visible and very far from being nonhomogeneous.

This experiment shows that even if the matter has a discontinuous structure (i.e., is composed of tiny particles that cannot be further subdivided without an alteration of the substance), its structure cannot be observed unless a much greater subdivision occurs than is obtainable by dissolving the fluorescein in water. It is, therefore, apparent that the molecules—the smallest particles into which a substance can be subdivided—are very small.

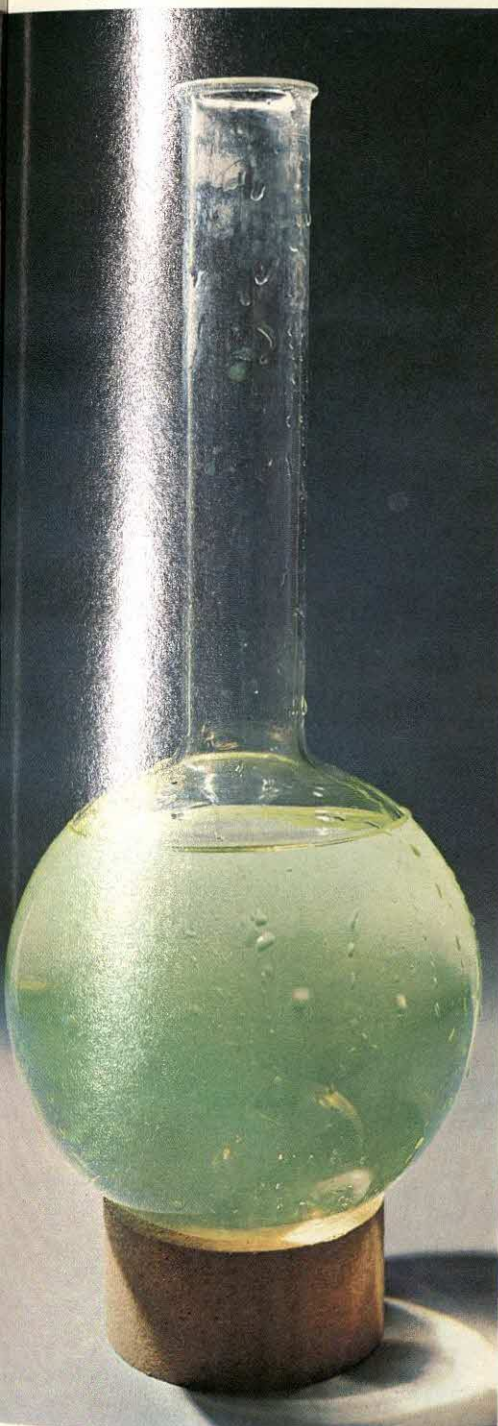
1a



1b



1c



1d



1e



THE EXISTENCE OF MOLECULES—A simple experiment provides evidence, although indirect, of the existence of molecules. If a solid is cut up into smaller and smaller pieces, the smallest particle of which the substance is made up cannot be isolated. Liquids, however, offer evidence of molecular isolation. A small quantity of triolein, $\text{C}_3\text{H}_5 \cdot (\text{C}_{18}\text{H}_{33}\text{O}_2)_3$, is dissolved in ether, in which triolein is exceptionally soluble. After a little talcum powder is sprinkled on the surface of some water, a small drop of the triolein-ether solution is poured into the water surface. The drop expands, the ether evaporates immediately, and the triolein forms a thin membrane on the surface. The phenomenon cannot, of course, be observed where the talcum powder is thickly spread on the surface of the water, but only where there is the merest film of it. If the solution were highly diluted, the membrane would be so thin as to be almost invisible. Its outlines, however, can be observed where the talcum powder has been pushed aside as it

expanded on the surface of the water. If the concentration of the triolein-ether solution is known and the extension of the spot on the surface is measured, the presence of the talcum powder permits the thickness of the drop to be determined. It is now possible to observe the force with which the drop expands on the surface of the water and to observe that, if the drop is allowed to expand indefinitely, a point is reached at which expansion becomes minimal. If the matter had a continuous structure (if it were not made up of molecules), nothing of this sort could be observed and the expansion would continue indefinitely. The fact of minimal expansion suggests that the water is covered with a monomolecular stratum—a single layer of molecules, beside each other and in contact. The extension of each molecule can be measured in terms of Avogadro's constant, which is the number of molecules in one gram molecule of a substance. For all substances this number is approximately 6×10^{23} .

2



THE KINETIC THEORY OF MATTER—The existence of atoms and molecules can be demonstrated by simple experiments. Atoms are the smallest particles of matter that compose the elements, and molecules are the smallest particles of compound substances; thus, a molecule is usually made up of many atoms.

A simple experiment shows that molecules are not fixed in matter but are in very rapid motion. If a small quantity of varnish is dropped into water, a milky suspension results (Illustration 4a). Under a powerful microscope (at least 1,000 X), the smallest particles of the suspension appear in continuous, irregular motion. The irregular motion of each molecule fluctuates around an average position and is caused by the collisions of the molecules. Illustration 4b shows how this irregular motion takes place: the solid line represents the typical path of a molecule, each abrupt change in direction indicating a collision with another molecule.

The kinetic theory of matter is based on the fact that matter consists of molecules in rapid continuous motion.



3b



AVOGADRO'S CONSTANT—Avogadro's constant (number) is used to state the number of molecules in one gram molecule of any substance. A gram molecule is a mass, in grams, numerically equal to the molecular weight of the substance. Avogadro's constant is a very sizable number. The following analogy (Illustration 3a) gives a general idea of its size:

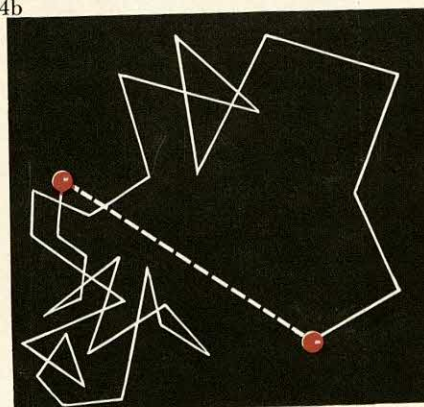
Suppose that the molecules in a glass of seawater could be marked in such a way that they could be easily identified. Assuming that it is possible for the water to be distributed evenly over all the oceans, the water is thrown back into the sea. If the glass is filled with this evenly distributed solution, a very large number of marked molecules will be found in the glass. In other words, a glass of seawater contains many more molecules than there are glasses of water in all the oceans of the Earth.

The picture tube of a television set (Illustration 3b) is an electronic device from which most of the air has been removed. A small picture tube has a volume of about 20 l (about 0.7 cu ft) and contains, before it is turned on, a number of molecules of air. Assume that a slight leak allows a little air to enter the vacuum at a rate of a thousand million molecules per second. It is reasonable to assume that such a high rate of re-entry would cause the tube to stop functioning, but this is not the case, even though as many as 30,000 million million (3×10^{16}) molecules would enter the tube in one year. The tube will, of course, eventually refill and stop functioning; however, this illustrates the magnitude of Avogadro's constant, for 20,000 years would pass before 6×10^{23} molecules entered the tube.

4a



4b





PART 8

- 135 Engineering Giants
- 140 The Transmission of Electric Power
- 145 Human Levers
- 148 Television

APPLIED SCIENCES | the way things work

Throughout this volume—and in Volumes 2 through 16 that follow—we have concentrated on the theory and basic principles underlying each major area of scientific knowledge. The laws of physics, chemistry and mathematics have, through man's ingenuity, evolved through the centuries until they are now familiar to every student and follower of whatever discipline one chooses.

But theories alone cannot help mankind to progress unless and until they are applied—that is, man must convert the principles of cinematographic projection into black-and-white television; he must transport huge amounts of electrical energy across hundreds of miles to bring a source of power into homes and industry alike; and he must build huge dams in order to make that power available. This is what we mean by “applied science”; it is the technology that produces the raw materials that are converted—via hundreds of different processes—into the materials and machines that man needs to exist in a modern society.

Until the eighteenth century, man's technology consisted solely of craft skills—the use of simple hand tools and the natural power sources of wind, water and fire. We began with sticks and stones, from which we fashioned crude tools with which to kill animals and grow crops for food. Indeed, the ages of man take their names from our evolution as a tool-producing creature—beginning with the Paleolithic, or Old Stone Age, and extending to the Neolithic, or New Stone Age. The Bronze Age, which began about 4000 B.C. in the Near East, contributed copper and bronze, the harnessing of animal power, wheeled vehicles, the sailboat, the potter's wheel and bricks. Once man learned how to use metals, he developed the principles of practical metallurgy that spawned the first engineers.

With the development of urban societies in the rich Tigris-Euphrates and Nile Valleys, technological advances increased dramatically. The pyramids stand today as a landmark of this prog-

ress, as do the ziggurats, the great city walls, and the obelisks. The Greeks and Romans contributed roadbuilding, shipbuilding and the great Roman aqueducts.

The flowering of European technology, from which stems our modern era, had as its landmark the genius of Leonardo da Vinci, whose mechanical sketches were those of a practicing engineer. The invention of the printing press in the fifteenth century heralded the tremendous sociological and political changes that were to sweep the Western world during the seventeenth and eighteenth centuries. The development of the steam engine was one of the prime movers in the industrial revolution, along with the creation of an international cotton industry and the factory system of production.

Gradually, as man's knowledge of technology accumulated, he learned how to use matter and energy for his own benefit—until the world's scientists were ready to make the incredible leap forward that has characterized the twentieth century. The internal combustion engine, the hot blast furnace, the electric light, the telephone, all these and countless other innovations helped move man forward at an ever-accelerating pace until, by the mid-twentieth century, he was forced to stop and take note of the consequences of this technological progress. For now the spectre of air and water pollution—a direct result of man's technological success—threatens our very existence. Ironically, science must now turn its inventiveness against itself, so to speak, in order to tame and humanize the same machines that it had so recently created.

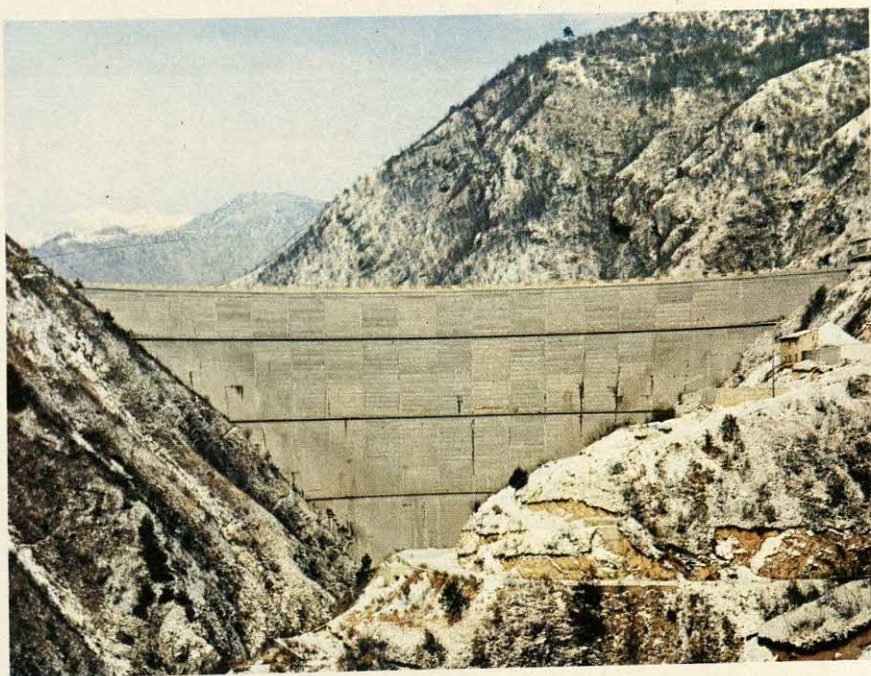
In the pages that follow—and throughout Volumes 17 and 18—more than 75 articles analyze in depth *the way things work*. Such diverse topics as the telephone, the x-ray, the laser beam, radar and nuclear energy have been compiled alphabetically to help readers understand how the laws and principles of science have been converted into the machines and industrial processes that we have come to take for granted.

ENGINEERING GIANTS | controlling millions of cubic yards of water

The Grand Coulee and Hoover Dams are considered among the greatest engineering accomplishments in the United States. These magnificent structures are the twentieth-century products of man's long continuing efforts to control and exploit water resources. Records indicate that huge earthen dams on the Tigris and a large masonry dam on the Nile were built in almost prehistoric times; and we know that the Romans built many large masonry dams in northern Italy and northern Africa.

To exploit the water resources of a valley, a dam is built to regulate water flow through the valley. The volume of this flow fluctuates during the year because of seasonal variations in rainfall, melting snow, and ice. A dam blocks the water and forms a reservoir; the level of the reservoir is, in turn, controlled by channels or spillways. The impounded water can then be used for irrigation or to generate electricity by turning turbines in power plants.

Forming a large watercourse can create a reservoir as large as the largest natural lakes. In the case of the huge artificial lakes of the United States and Soviet Union, these reservoirs may hold billions of gallons of water. The Grand Coulee Dam represents civil engineering at its highest level. Awesome in size, it contains about 8 million cubic meters (nearly 10.5 million cubic yards) of concrete—seven times the volume of the masonry in the Great Pyramid of Khufu



NARROW VALLEY BLOCKED BY AN ARCH DAM—Artificial lakes, sometimes enormously

large, are formed upstream of dams such as the one shown here.

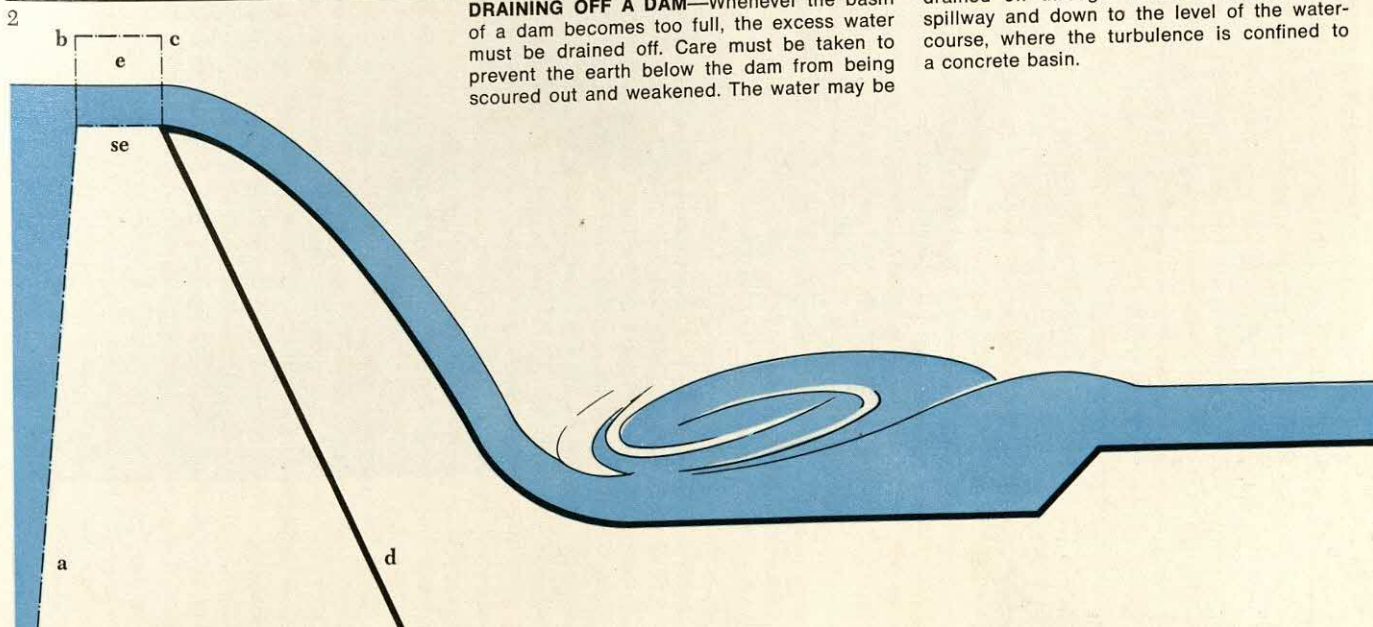
(Cheops)—making it the largest masonry structure in the world. A dam such as this one must be built to withstand enormous water pressure and, sometimes, the pressure from the mountain slopes against which the shoulders of the dam may rest. Believed to be among the most enduring structures ever built, the Grand Coulee should last hundreds of thousands of years—even without maintenance.

GENERAL STRUCTURE

No two dams are alike. The form of each dam depends on the shape of the valley in which it is built, on its abutments, on the amount of water it is to contain—even on variations in temperatures to which it will be subjected. But all dams have something in common in the general way in which they are built,

DRAINING OFF A DAM—Whenever the basin of a dam becomes too full, the excess water must be drained off. Care must be taken to prevent the earth below the dam from being scoured out and weakened. The water may be

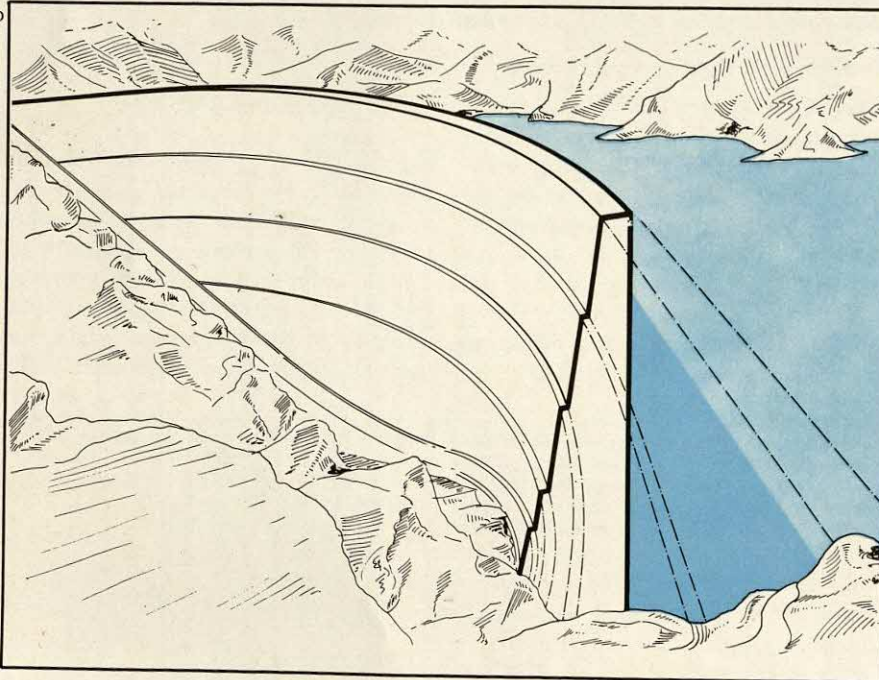
drained off through overflow outlets onto a spillway and down to the level of the watercourse, where the turbulence is confined to a concrete basin.



3a



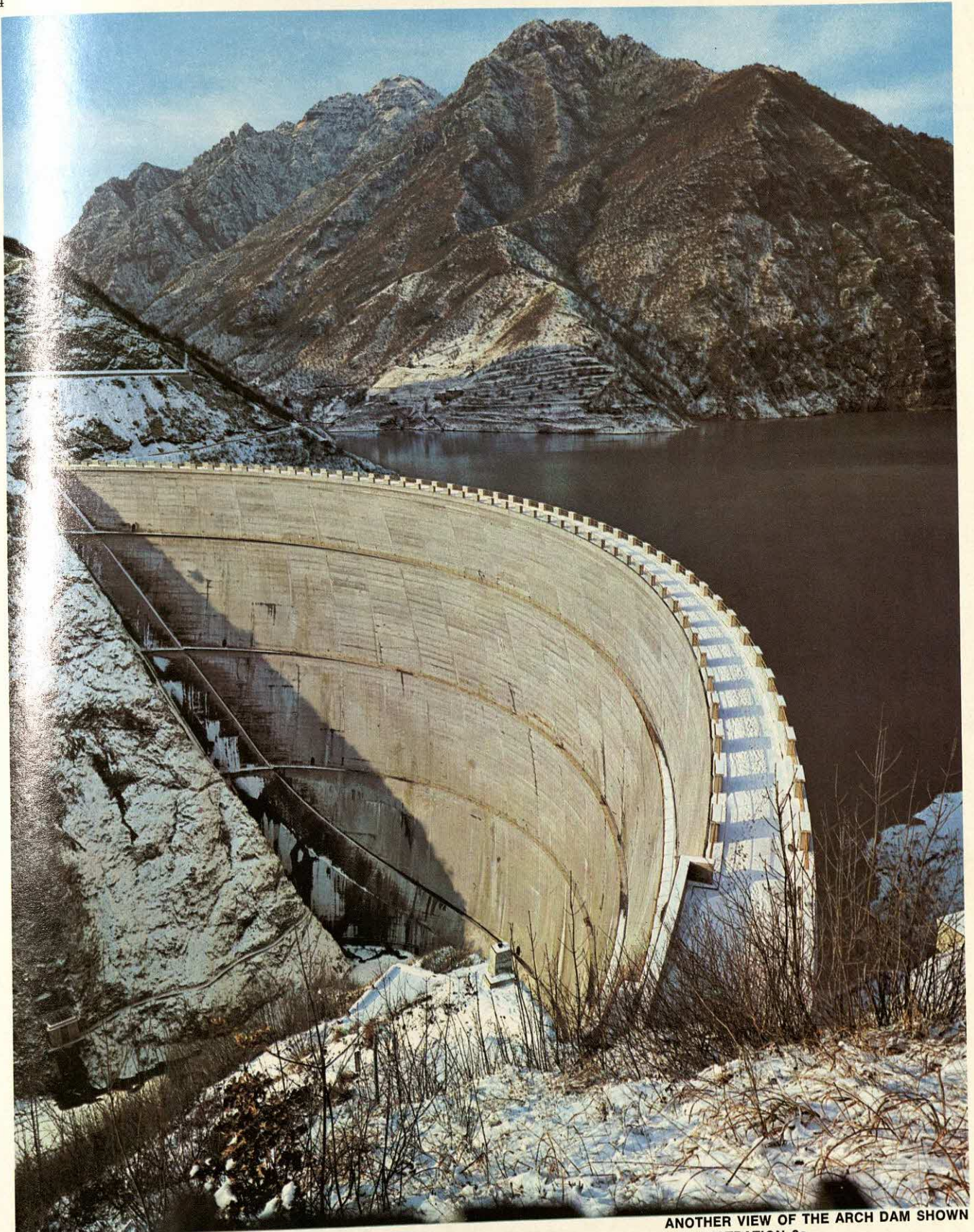
3b



ARCH DAMS—Arch-dams such as that shown in Illustrations 3a, 3b and 4 are chiefly used to block deep, narrow valleys. Dams of this type withstand water pressure by distributing the pressure of the water over the walls of the valley abutting them. They are generally higher

and thinner than gravity dams, although equally strong. The various degrees of thickness (Illustration 3b) distribute the water pressure equally over the entire surface of the dam. The arch dam illustrated is located in the Valvestino province of Brescia, Italy.

making it possible to diagram the general structure of a dam (Illustration 2). The lines a b c d show the typical structure, in cross section, of a dam. The dam is thickest at the base, which has to bear the entire weight of the structure and where the pressure of the water is greatest. The section approximates a scalene trapezoid topped by a rectangle e. The two ends resting on the side of the valley are the abutments; e is the crown, the upper limit of the dam. The crown is usually rectangular and is often topped by a road used by maintenance vehicles. The letters se indicate the overflow outlets or spillways. When heavy rainfall fills the dam basin to overflowing, the excess water must be drained off without overtopping the crown. If the water were allowed to overflow unchecked, it might damage the crown. Channels are built to drain off excess water when sluice gates are opened. Occasionally pipes are cut into the body of the dam itself, rather than into the crown. Study of the discharge records of a stream and of local flood possibilities determines the required capacity of a spillway.

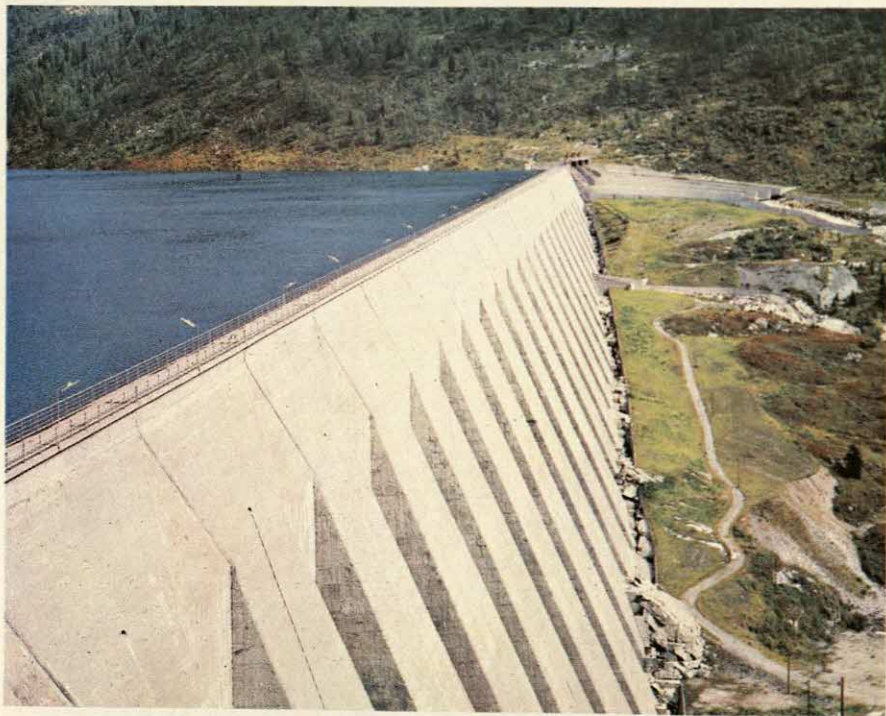


ANOTHER VIEW OF THE ARCH DAM SHOWN
IN ILLUSTRATION 3a

5



6



GRAVITY DAMS—The Aswan High Dam (Illustration 5) in upper Egypt is 1,962 m (about 6,400 ft) long and impounds a reservoir with a capacity of 155 billion cubic m (about 126 million acre-ft). This dam controls the once disastrous annual flooding of the river Nile.

The Malga Bissina Dam (Illustration 6) at

Valdifumo, Italy, is a gravity dam with the characteristic rectilinear form and triangular cross section. Gravity dams resist extremely high water pressures with their weight alone, and are especially suitable for blocking wide, shallow valleys.

TYPES OF DAMS

Small dams are occasionally built of earth. Although quite common, earth dams are relatively weak structures because of the gradual eroding effect of the water. Layers of fine clay (which is fairly waterproof but is lacking in cohesion and, therefore, liable to erosion) are sandwiched between layers of sand and gravel. The dam is usually surfaced with stone slabs, although layers of waterproof material can also be used. So that the dam will not break, great care must be taken to prevent water from seeping into the structure and gradually eroding the waterproof materials. The height of earth dams is comparatively limited, although earth-fill dams as high as 225 feet have been built in the United States and China.

The strongest dams are built of concrete and are of two types: gravity dams and arch dams. Gravity dams (Illustrations 5 and 6) are rectilinear and are often built of large overlapping blocks of concrete or stone with joints waterproofed with tar. The cross section of a gravity dam is a scalene triangle arranged so that the side nearest the vertical is the one against which the water presses. (The term scalene triangle is often used to describe the cross section because the shortest base of the triangle is quite small.) The side with the gentler slope faces down the valley (Illustrations 7a and 7b).

The body of the dam is subjected to two main forces: its own weight and the pressure of the water in the basin. The weight of the dam tends to keep it in position and the pressure of the water tends to overturn it. Illustration 8a shows that a dam with a right-angled triangular section with its vertical side facing the water would have to be lifted through a large angle to be overturned. If, on the other hand, the sloped side faced the water (Illustration 8b), the angle through which the body of the dam would have to be lifted decreases con-

siderable. No dam is going to overturn completely, of course. The point is that only a slight undermining of the body of the dam by the water can cause serious damage to the whole structure. Dams built with the gentler slope facing down the valley to give them greater stability are called gravity dams because their own weight withstands the pressure of the water. Such dams are particularly suitable for wide, shallow valleys; Grand Coulee Dam and the Aswan High Dam in Egypt are outstanding examples of this type.

Arch dams—which are used chiefly to block deep, narrow valleys—consist of a spherical vault abutting the walls and floor of the valley in such a way that the concave side of the dam faces down the valley and the convex side faces the water. Like a gravity dam, an arch dam is thicker at the base than at the crown or crest. In the case of a dam 325 feet high and 325 feet long, the water may exert a force of about 500,000 tons against the base of the structure. This force tends to compress the dam and press it against the walls of the valley.

Because it withstands water pressure by distributing water pressure against the walls of a valley, an arch dam may be lighter in construction than a gravity dam—an advantage when the dam must be built in a remote, mountainous area. Matilija Dam in California is an outstanding example of such a structure.

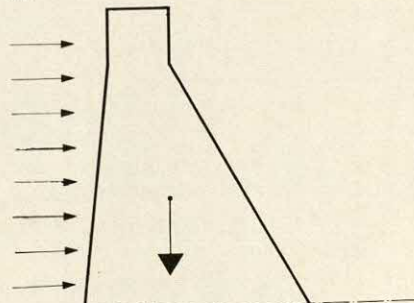
DELICATE GIANTS

If a dam gives way, the water released sweeps down the valley to leave death and destruction in its wake. Engineers and builders are obligated to exercise extreme care in planning, building, and operating dams. Most important is the care required in the design of the supports, or foundations, on the floor and in the walls of the valley. The dam must rest on its foundations in such a way that water cannot seep between the body of the dam and the floor or walls. If seepage

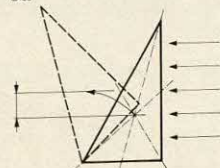
7a



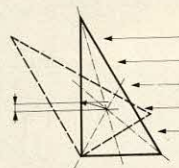
7b



8a



8b



SECTION OF A GRAVITY DAM—Gravity dams, with their characteristic triangular cross section (Illustration 7a), are heavy enough to remain firmly anchored to the floor of the valley (Illustration 7b) and to resist the thrust of the water that might otherwise overturn them. A dam with a triangular section is unlikely to overturn if the water presses against its vertical side (Illustration 8a). If the thrust were on the opposite side (Illustration 8b), the dam would overturn more easily.

does occur, the water eventually forces open a passage and undermines the dam at its base.

Dams are often built high in the mountains where construction is limited to those months in which wet concrete will not freeze, because frozen concrete does not set properly. If the temperature is

not too far below the freezing point, freezing may be prevented by covering the wet concrete with plastic material and blowing hot air between the cover and the body of the dam.

The concrete is poured in sections, rather than in one whole block, to allow the concrete space in which to expand and contract according to temperature changes. As it sets, the concrete generates some heat and its temperature rises. After the setting is complete, the temperature of the concrete falls to that of the surrounding air. This cooling process could cause cracks that would then become outlets for water. However, allowances are made for size changes; and cracks are avoided by dividing the structure into blocks resting on each other and sealed together with tar.

To record temperature differences between parts of the structure—differences indicating any danger of undue stress or cracking—thermometers are incorporated into dam structures. A medium-size dam may incorporate as many as a hundred thermometers.

The large mass of a gravity dam leads to complications in the concreting operations. The heat generated by portland cement reacting with water, for example, is not a problem for thin sections; but this heat of hydration must be dissipated in large dams by embedding in the concrete elaborate systems of cooling pipes. Two other methods that have been useful in controlling the development of heat are the fanning of aggregate stockpiles and the addition of crushed ice to the concrete mixtures as part of the mixing water.

New methods used in construction of the highest concrete gravity dam in the United States—the Dworshak Dam on the Clearwater River in Idaho—include radio-controlled, high speed cableways for rapid replacement of concrete; a new system of self-raising forms; installation of an underground rockcrushing plant; and an electronically controlled aggregate plant.

THE TRANSMISSION OF ELECTRIC POWER

transmitting light and heat by cable

Two of the world's largest hydroelectric generating stations are those erected at the Grand Coulee and Hoover dams. These stations are the source of a vast amount of electric power that is readily converted to light and heat. And yet, without the means to transmit this power over great distances, the value of these and other stations would be sharply reduced.

Hydroelectric stations are often, by necessity, located in remote mountain areas far from the cities and industries where the need for electric power is greatest. Steam-turbine powered generating plants are usually built near their fuel sources—close to natural gas fields, or coal mines—or sometimes near river- or seaports where electricity is most required. Technology has made it more economical to move the electricity from plant to consumer than to transport fuel long distances from its source to a generating plant.

Electrical power requirements—particularly in highly industrialized countries—vary greatly from hour to hour and from

day to day. In response to local requirements power is often diverted from one area to another.

HIGH-VOLTAGE TRANSMISSION

The amount of power that a generating station is capable of supplying per second depends on the size of its plant. Electric power is often measured in kilowatts (kw), which are units of 1,000 watts; one kw equals about 1.34 horsepower, approximately equivalent to the work required to raise a weight of 100 kg (about 220 lbs) through a distance of 1 meter per second.

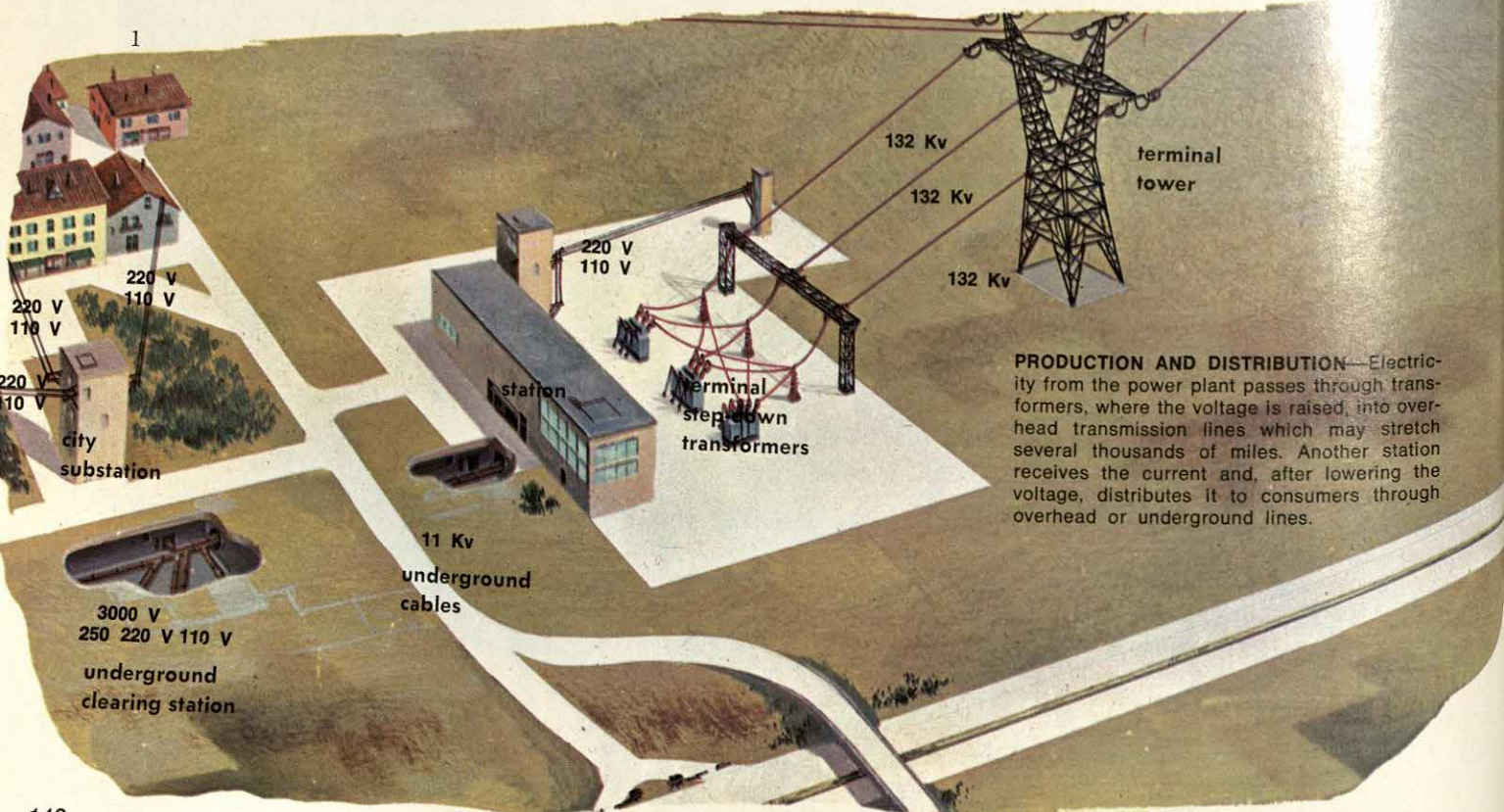
The power of an electrical source is expressed in watts and calculated by multiplying the voltage that the source is capable of supplying by the current (in amperes) it produces. A source supplying 1,000 amperes at 10,000 v supplies 10,000,000 watts (10,000 kw).

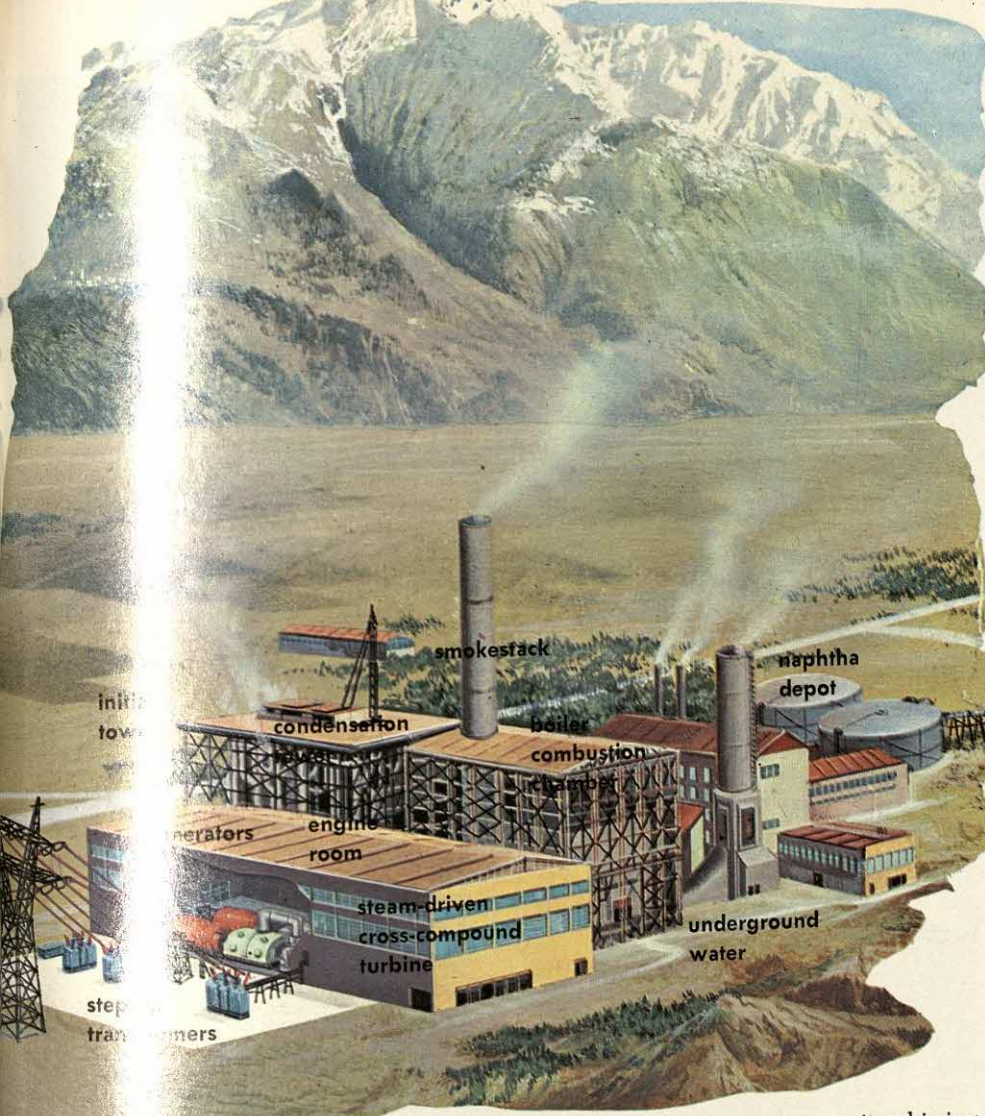
An electric cable can carry the same power in two ways: with a high number of volts and a low number of amperes (high voltage and low current), or with

a low number of volts and a high number of amperes (low voltage and high current). The combination of high voltage and low current is more practical. When electric power passes through a conductor, part of it is transformed into heat and is no longer usable as electric power. This loss increases in proportion to the amount of current carried and in inverse proportion to the diameter of the conductor; consequently, electric cables having small diameters are more economical than those with large diameters when high voltages and low currents are carried.

GENERATORS, TRANSFORMERS, AND MAXIMUM VOLTAGE

High voltages used for the transmission of electric power are usually 9,000 v and 230,000 v (the latter is a satisfactory over long distances). A problem hinges on the fact that the voltages are not within the range of power actually generated. The voltage of the power generated by alternating current





and, in many cases, by the need to withstand mechanical stress.

Electric cable is subject to several kinds of mechanical stress, notably the weight of the cable itself and the wind. If the distance between the supporting towers is several hundred yards, the stress may be significant. It becomes many times greater when the cable ices up, increasing in weight and diameter, or is blown by high winds—conditions common in mountain areas in winter.

Also subject to severe stresses are the metal towers or poles that support the cables, which are attached to the insulators. The conducting cable must be insulated from the tower because the latter is grounded; otherwise, the electricity would be conducted to earth by the tower metal.

The insulators, which are made of glass or porcelain, must have special mechanical and electrical characteristics to withstand the weight of the cables, the added stress caused by ice and wind, and the high voltages carried by the cables. Typical insulators consist of sev-

generators driven by hydraulic or steam turbines is on the order of 10,000 v. Any higher value is impractical because it would require generators of enormous size to house the thick layers of insulation required for the various windings, and because the problems inherent in moving parts would limit the size of the generator.

The comparatively low voltages produced by electric generators are raised for long-distance transmission and lowered when the power reaches the consumer area. The variations in voltage are produced by static transformers that are often enormous because of the thick layers of insulating material required and the large amounts of oil needed to cool them (a small percentage of the power transformed is dispersed in the form of heat).

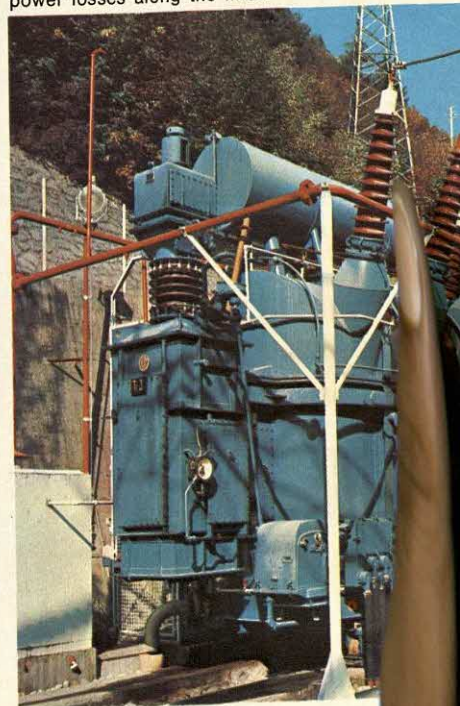
Although high voltages are more satisfactory than low voltages for the transmission of electric power—because they involve less expensive electric cables and smaller power losses—high voltages cause knotty problems of insulation. High-

voltage cables sometimes emit a hissing sound or glow (because of the corona effect) caused by a partial electrical breakdown or ionization of the air around the cable. Corona effect power losses become appreciable at 300,000 to 400,000 v. Despite this, cables carrying as many as 380,000 v are used in the United States, the Soviet Union, and Sweden. In the late 1950s the Soviet Union announced plans to construct an 800,000 v transmission system to carry direct current about 300 miles.

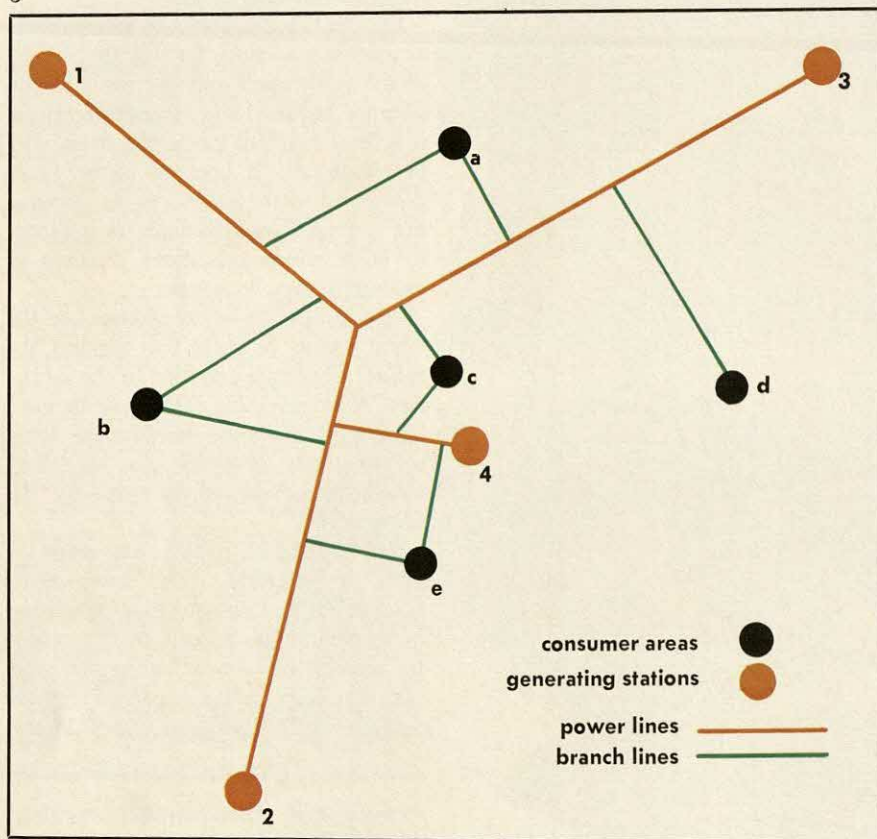
TOWERS, INSULATORS, CABLES

Long-distance power transmission lines are made of plaited strands of conductive material such as copper or aluminum. Where high mechanical resistance is required, the cable contains a steel core—particularly if the conductor is aluminum, which is mechanically weak. Held aloft by steel towers or poles, the cables are not covered with insulating material. The diameter of the cable is determined by the amount of current to be carried

THREE-PHASE TRANSFORMER—Transformers, such as the one shown here, are used to raise the voltage of power generated so that the diameter of the transmission cables can be kept to a minimum, thereby reducing power losses along the lines.



3



INTERCONNECTING NETWORK—The diagram shows how four generating stations (1 2 3 4) are linked to consumer areas (a b c d). The brown lines represent the power lines along which electric power is carried; the green lines are the branch lines which carry power from the main network to the consumption points. Consumer area d normally receives power from station 3—although it could also

receive it from one of the other stations if station 3 were shut down for any reason, if its transmission line was interrupted, or if it did not produce enough power to meet the requirements of area d. In this case the power to d would be more expensive because it would have to be brought from a greater distance.

eral disks of glass or porcelain held together by mechanical fittings. Some parts of the lateral surface of the insulator are always dry; in other parts water collects in separate drops that cannot conduct electricity because of the distance between them.

Insulators undergo careful laboratory testing in which increasing amounts of voltage—far higher than those experienced under actual conditions—are passed from one end of the insulator to

the other to determine at what voltage discharge takes place. When discharge does occur, it must do so well away from the body of the insulator; otherwise, the surface is conductive and the insulator unsuitable.

DISTRIBUTION TO CONSUMERS

Steel and iron industries, which are usually located some distance from densely populated areas, use electric power at

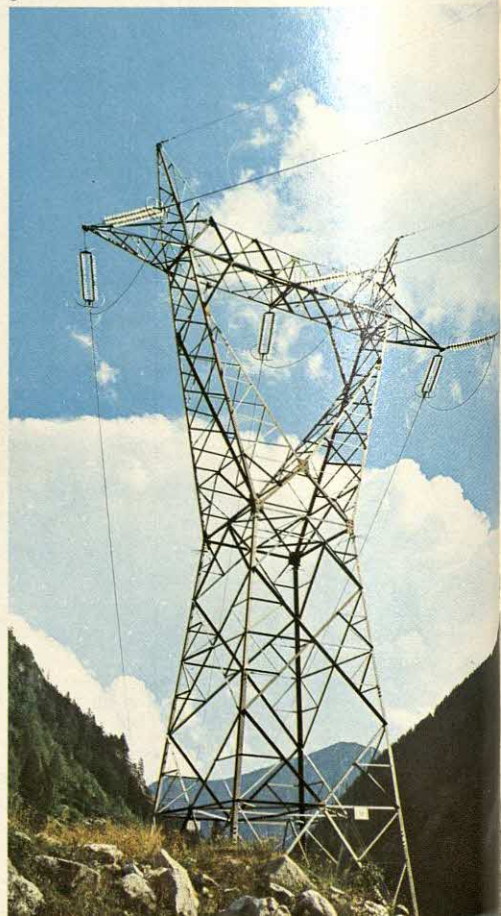
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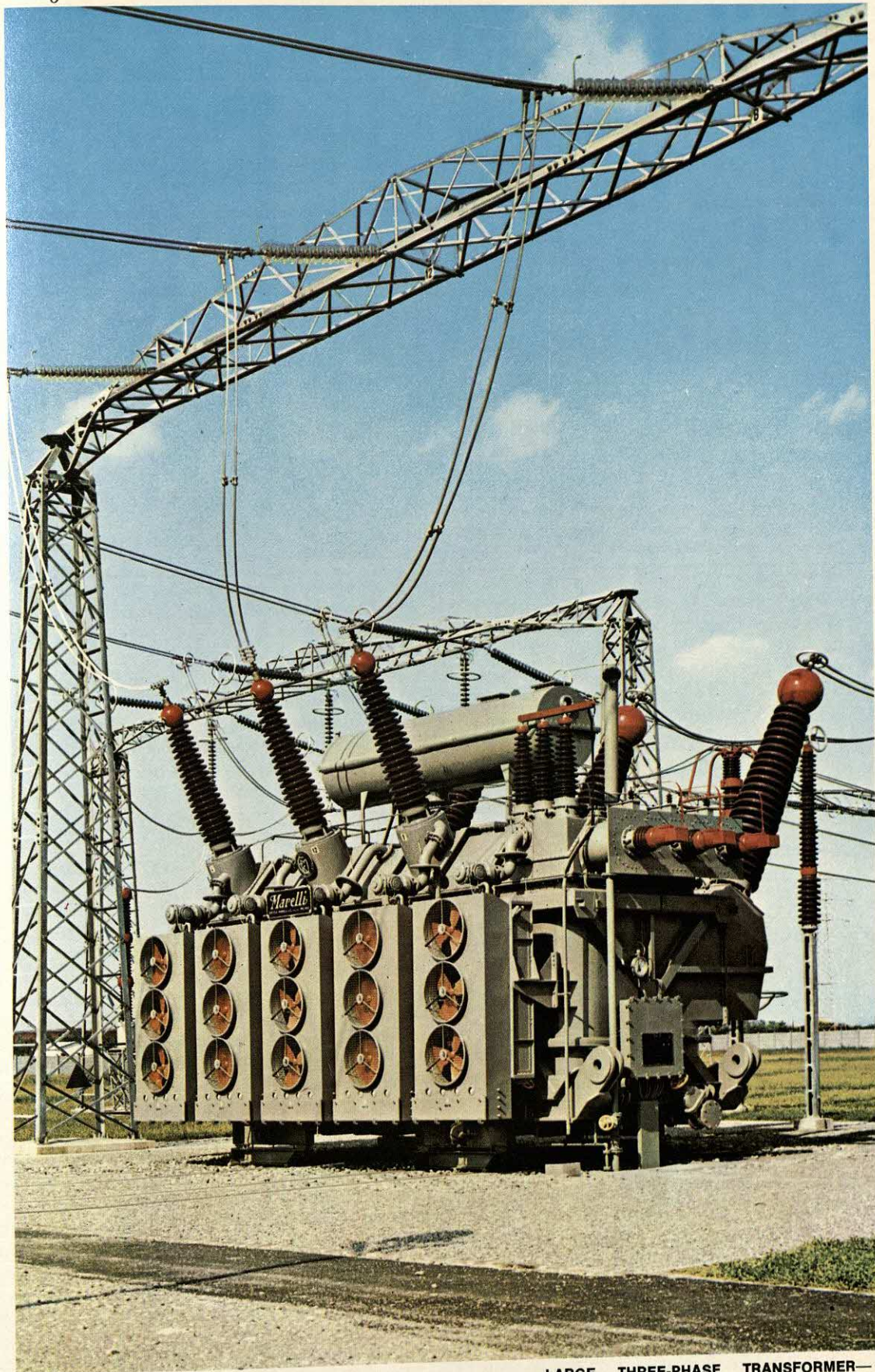


INSULATORS—Located between the transformer and the power line, these insulators consist of tiers of porcelain disks with very high insulating and resistance properties.

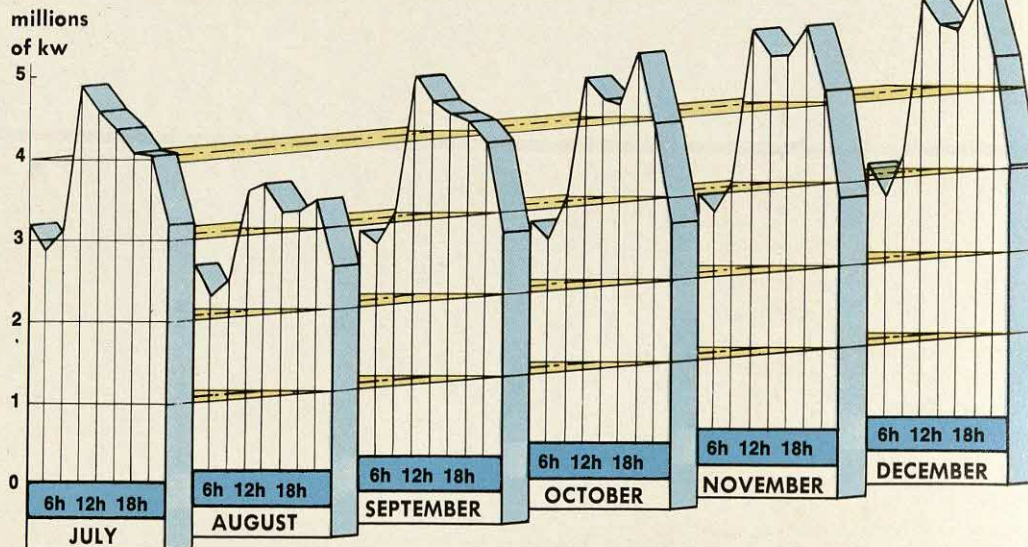
ELECTRIC TRANSMISSION TOWER IN MOUNTAIN COUNTRY—Resting on a concrete platform, this tower is constructed of shaped steel sections.

5





LARGE THREE-PHASE TRANSFORMER—
Every receiving station is equipped with transformers to lower the extremely high voltage of the current for consumer use.



LOAD DIAGRAM—The diagram is based on the third Wednesday of each month. Con-

sumption drops off in August, when industries close down for vacations, but rises in winter,

when lighting needs account for increased use.

comparatively high voltages. These industries can take current directly from a high-voltage power line and use a transformer to lower the voltage to the level required to operate the electric furnaces and the steam generating plant.

Supplying a city or an industrial area within an urban area is more complicated. Overhead power lines cannot be used. Even if they could be strung high enough, the potential danger from the uninsulated cables would be too great; therefore, they are laid underground. Although in exceptional cases underground cables can withstand extremely high voltages, their maximum voltage is usually a few thousand volts. High-voltage power lines are strung to a point on the outskirts of the city, where the voltage is reduced by transformers so that the underground cables can carry the current into the city.

Once reduced to this voltage level, the power can be conducted to all parts of the city; but it is not yet ready to be distributed to homes, where a level of a thousand volts is still too dangerous. The voltage is reduced again by another set of transformers located as near as possible to the consumer area; this is done to avoid carrying power over excessive distances at low voltages, which would result in costly power losses. This also explains why each district in a large city is equipped with a substation to reduce

the voltage. A substation consists of enclosed transformers and safety switches from which power lines branch off to consumer areas. Smaller transformers mounted on poles further reduce the voltage to 115 or 230 v, at which point it becomes suitable for ordinary use.

LOAD DIAGRAMS AND THE COST OF ELECTRIC POWER

Suppliers of electric power take care to minimize power losses caused by overheating of conductors, but in even the most efficient lines about 1 percent of the power transmitted is lost. To avoid pumping water through steam generating stations, or burning valuable fuel when power is not needed, still greater care is taken to produce electric power only when it will be used. Thus, so-called load diagrams are drawn to show hour-by-hour power consumption. The work of generating-station personnel would be much simpler if the load diagram showed a straight horizontal line—meaning that the load or consumption was constant—because then the generators could be operated at a constant speed. But every consumer, in effect, creates his own load diagram. The load imposed by iron and steel industries may be almost constant because they operate around the clock, but a peak load for medium and light industries stretches from morning

through early afternoon.

Generating-station personnel require advance data on load because it is not feasible to slow down or stop some types of power plants. Several hours may be required to start steam-turbine-powered generating stations, while hydroelectric plants can be started in only a few minutes. For this reason steam plants are used chiefly to produce the minimum amount of power needed throughout the day (the so-called average load). Power from hydroelectric plants—peak load power—is brought into the network at peak hours.

Distribution of electric power may vary according to the type of generating station prevalent in the area. The need to alternate power from steam-generating stations with that produced by hydroelectric stations clearly points up the advantage of equipping an entire country with a network capable of bringing in power from first one station, then another, according to requirements.

The cost of electric power depends on many factors. The cost of a kilowatt-hour produced in a generating station inevitably rises sharply—sometimes even doubles—by the time it reaches the consumer, depending on losses incurred along the power line, on depreciation of the line itself, on losses at transformers, and on waste caused by unnecessary production outside consumer hours.

HUMAN LEVERS

the simple machines
that govern body movement

The human body has often been compared to a machine—and like a machine it has certain moving parts. The skeleton, for example, acts much like several sets of levers. And while there is nothing in the human body that resembles a wheel, there are many marked similarities between man and the machine that help us to function with optimum efficiency.

But first, it is necessary to describe briefly the basic life process. With the exception of hair and claws, every part of an animal body requires a continuous supply of blood to bring it food and oxygen and to remove waste products. The entire animal body is permeated by a close network of minute blood vessels called capillaries, through which the blood flows and is distributed to every living cell of the body. These cap-

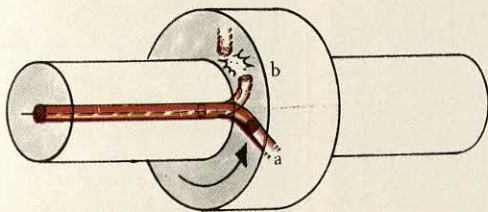
illaries are delicate and can be torn if they are stretched excessively. Once torn, they release their blood into body tissues in a condition known as hemorrhage. This disrupts the proper flow of blood throughout the body and the functioning of other body parts as well. Nerves and muscles, too, can be damaged if stretched beyond their limits. The human body and the bodies of other animals are so constructed that they can avoid these occurrences so long as they perform ordinary functions.

NO WHEELS IN THE ANIMAL KINGDOM

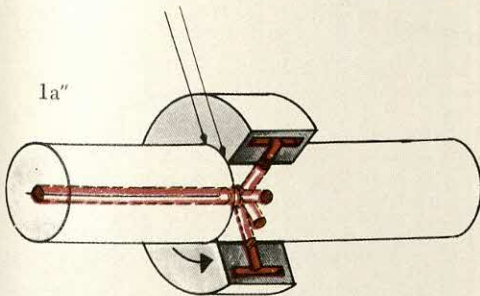
If the moving parts of the body included wheels, consider the damage that would surely occur during the process described

above: the blood vessels, nerves and muscles that terminated in (or on) a wheel would become hopelessly twisted and stretched as the wheel kept turning. The body does, however, contain many "levers"—the bones—that do not put such strains on body parts. A lever is a bar that pivots on one point along its length, and the point of pivoting is called the fulcrum. Located at one end of the bone, the fulcrum coincides with a joint. In living things the joints are capable of only a limited range of movement; the two bones connected by a joint rarely are able to rotate through an angle of more than 180° , and many cannot exceed 90° . Within these limits no undue strains are placed on blood vessels, nerves, or muscles which then are able to function without disruption.

1a'



1a''



1b

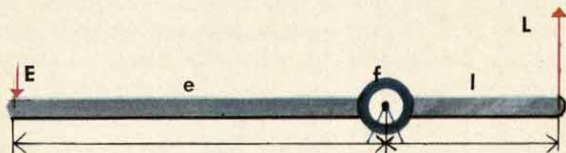


WHY ARTERIES AND VEINS ARE NOT TORN
—An animal body is not likely to be supplied with a rotating part, such as a wheel. If a wheel were supplied with a blood vessel running along the wheel's axis, however, the vessel would be broken as the wheel turned

(Illustration 1a'). Obviously this would not be an efficient way to carry nourishing blood to the rotating part. If the blood reached the wheel through holes drilled into the axis, as shown in Illustration 1a'', there would be still another problem: at the points shown by the

arrows blood would tend to escape.

In a joint with limited rotation, such as that of the knee, there is no risk of blood vessels becoming torn by the action of moving parts.



THE LEVER—Any bar that pivots on one point on its length is a lever. The point on which it pivots is the fulcrum. If the lever is moved by applying a force **E** (represented by an arrow and called the **effort**) at one end, this movement can overcome a load **L** (called the **resistance**) at the opposite end. In practice, the resistance usually is a weight to be raised.

The distance from the point of application of the force to the fulcrum is known as the effort arm; that from the fulcrum to the point of application of the resistance is known as the load arm.

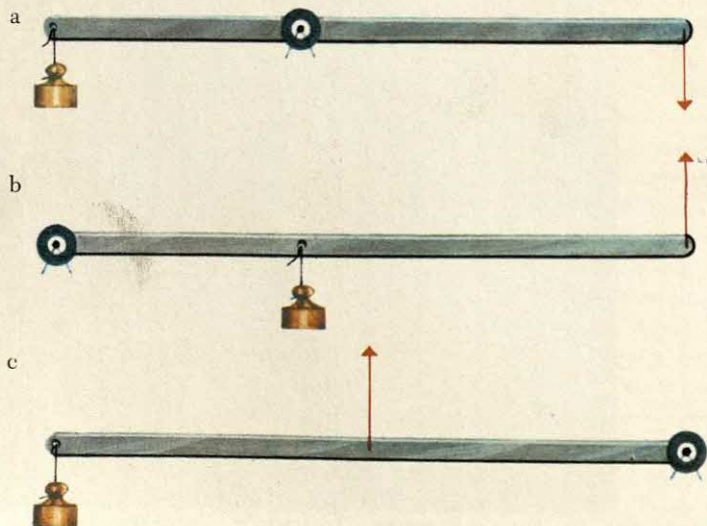
If the effort arm is longer than the load arm, the application of a small amount of force can overcome a very large resistance. Such a lever

is said to have a mechanical advantage, for a small effort **E** overcomes a large force **L**. The fulcrum illustrated here has a mechanical advantage. If the fulcrum were moved to the left so that the load arm became longer than the effort arm, a large amount of force would have to be applied to overcome a small resistance. Such a lever has a mechanical disadvantage.

The relationship between forces and lengths of arms is expressed by the formula $Ll = Ee$, where e is the length of the effort arm, and l is the length of the load arm. This formula may be applied to all the levers shown in Illustration 3.

TYPES OF LEVER—The three types of lever are classified as to where the fulcrum, effort, and load are applied. In a first class lever (Illustrations 2 and 3a), the fulcrum is between the effort and the load. In a second class lever (Illustration 3b), the fulcrum is at one end of the lever, the effort is at the opposite end, and the load is between them. The effort arm

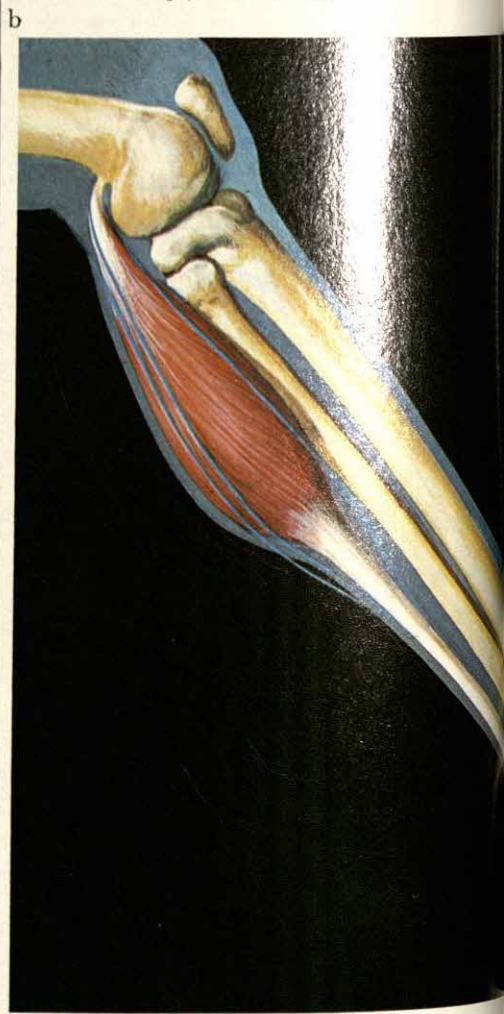
is the entire length of the lever. A second class lever always has mechanical advantage. In a third class lever (Illustration 3c), the fulcrum is at one end, the load is at the opposite end, and the effort is between them. The load arm is the entire length of the lever. A third class lever always has mechanical disadvantage.

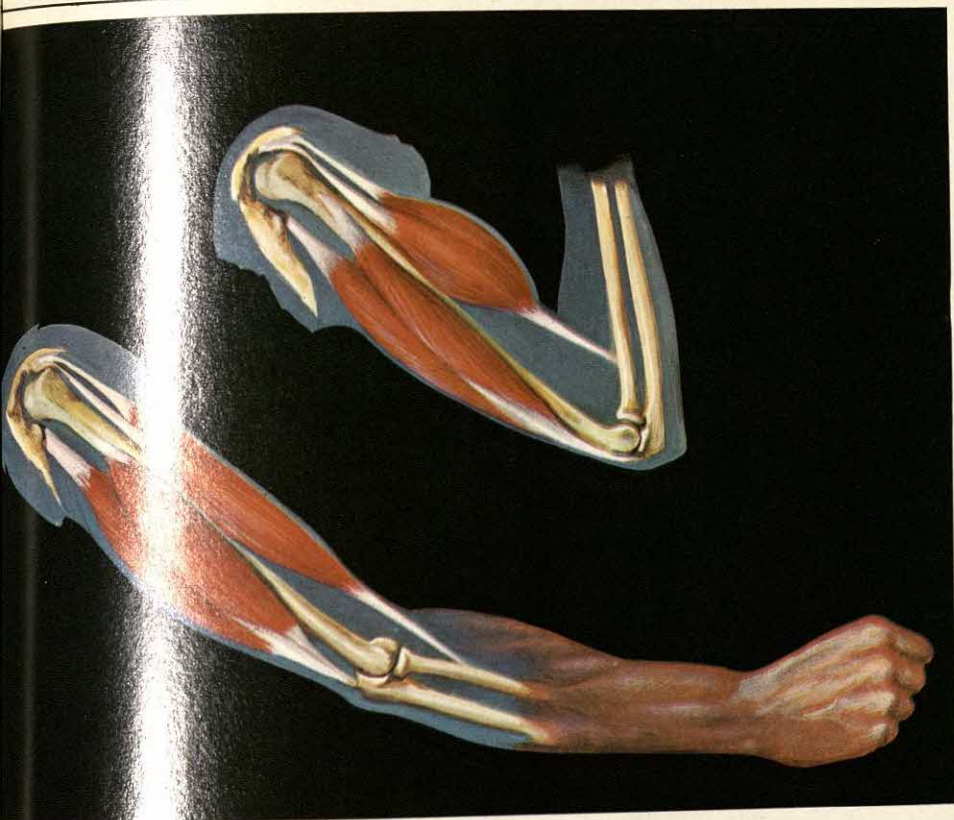


LEVERS OF THE FIRST, SECOND AND THIRD CLASS

The human arm contains examples of both first and second class levers. The forearm is extended by the triceps muscle and retracted by contraction of the biceps muscle (Illustration 4a). In both cases the elbow is the fulcrum, and the hand is the load. The extension of the arm is the operation of a first class lever, for the hand and the point of attachment of the triceps to the forearm are on opposite sides of the fulcrum (the elbow). The retraction of the arm, on the other hand, is carried out by a third class lever, for the point of attachment of the biceps, which is the effort, is between the fulcrum and the load (the hand). Both of these levers have strong mechanical disadvantage, for the load arm (elbow to hand) is eight to ten times as long as the effort arm (elbow to the point of insertion of the appropriate muscle).

If one holds his elbows at his sides and keeps his forearms in a horizontal position, then a weight of 20 kg (about 44 lbs) placed in each hand extends the biceps muscles with a force of 200 kg (about 440 lbs).



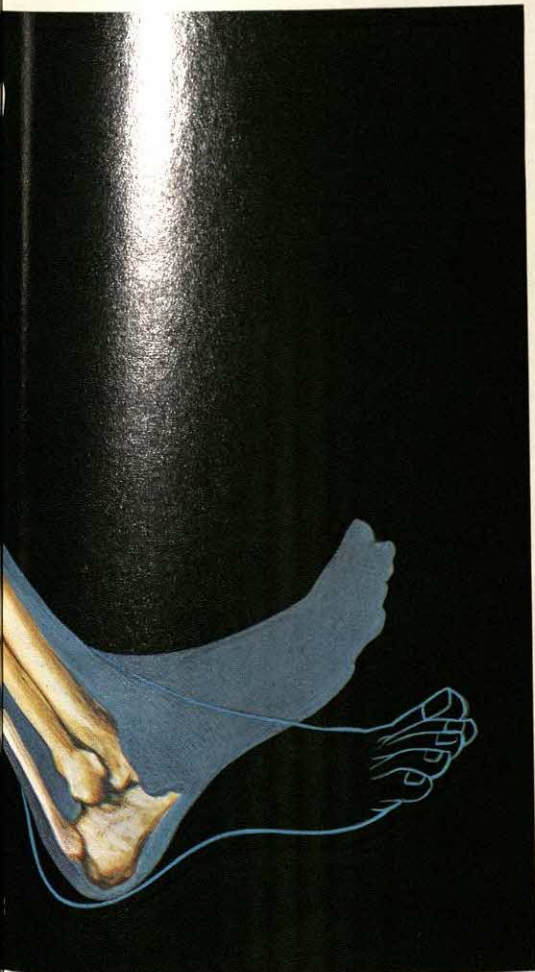


a

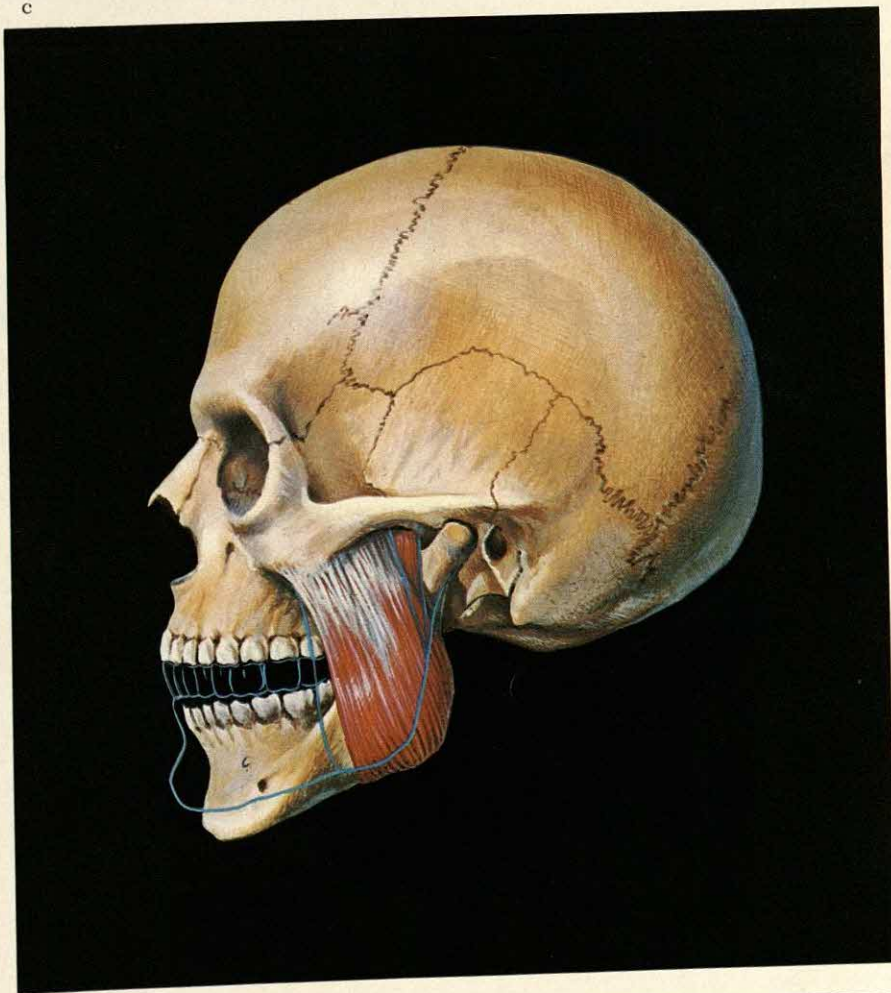
The gastrocnemius muscle of the calf (effort), heel (fulcrum), and foot (load) comprise another example of a first class lever in the human body (Illustration 4b).

The jaw (Illustration 4c) is an example of a second class lever. The fulcrum of the jaw is situated in its two upper extremities, near the ears. The muscle that tightens it is the masseter, which is attached to the jaw almost at the chin. This muscle, which represents the effort, exercises its force by raising the jaw. The load becomes the force that the jaw, which has a strong mechanical advantage, exerts on food between the molars. It is of little importance that mastication be rapid, but it is important that a strong effort be exerted.

The strength of the force developed by the jaw is occasionally demonstrated by acrobats who hang onto a ring by their teeth and carry out exercises with the entire weight of their bodies suspended from their jaws.



c



TELEVISION | the dots create the picture

The picture that appears on a television screen is based on the concept of breaking down the images into a series of dots, each of which is converted into an electric signal proportionate to its brightness. It is a process analogous to that used in halftone photoengraving—as, for example, in newspaper reproductions of photographs. The organized sequence of dots on the television screen gives the impression of a complete picture because the image persists on the retina of the eye—that is, the brightness of the first dot is still perceived when the last dot of the frame appears. This result is possible only when the production of dots is very rapid. In the United States, 30 complete frames of pictures are transmitted every second, each frame consisting of 525 horizontal lines.

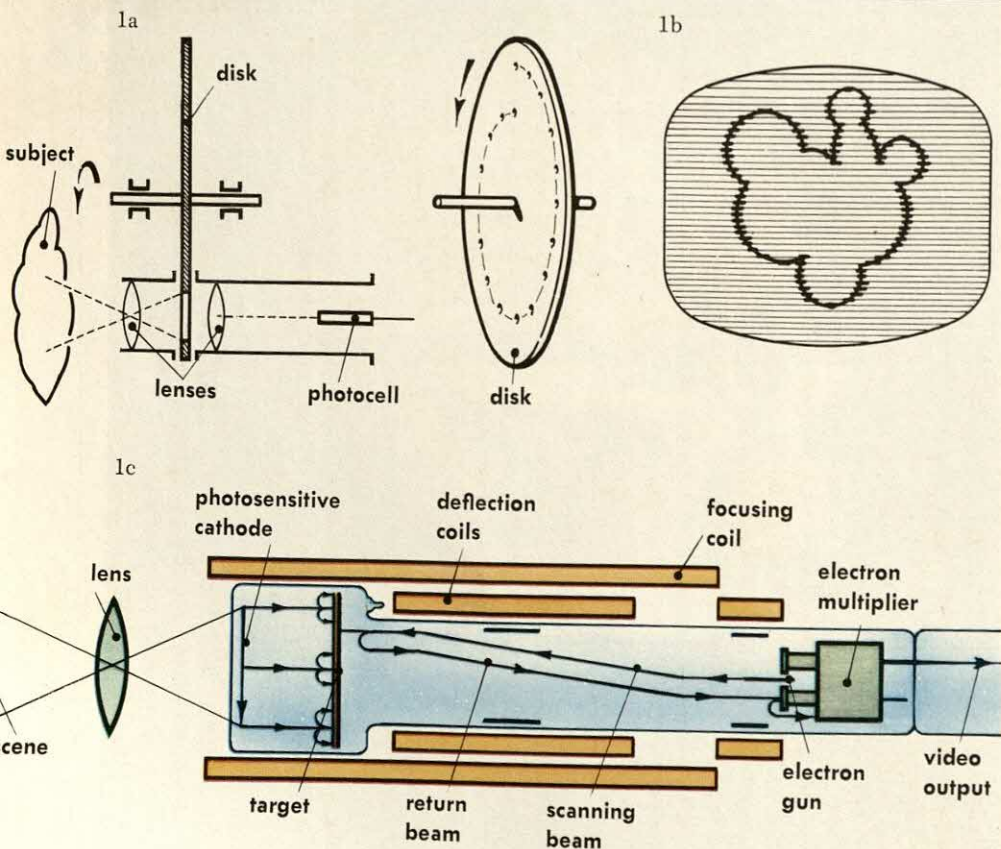
A transmission is not complete, however, without an audio (sound) signal. This means that many more signals must be transmitted than would be required

for a radio broadcast, and so television broadcasting needs a much wider frequency band. An AM (amplitude-modulation) radio station uses a 12-kilocycle band, and an FM (frequency-modulation) station needs a 150-kilocycle band; a television band, or channel, must have a width of six megacycles (6,000 kilocycles).

This bandwidth requires the use of very high carrier frequencies, with relatively short wavelengths (of the order of meters or decimeters). As a result, the range of a television transmitter is much more limited than that of a radio transmitter, because television waves travel directly from transmitter to receiver (radio waves can be reflected from the ionosphere) and are easily absorbed or reflected by natural obstacles. A line-of-sight, obstacle-free path is, therefore, required between the antennas of the receiving station and those of the transmitter or relay station.

THE CHARACTERISTICS OF TELEVISION TRANSMISSION

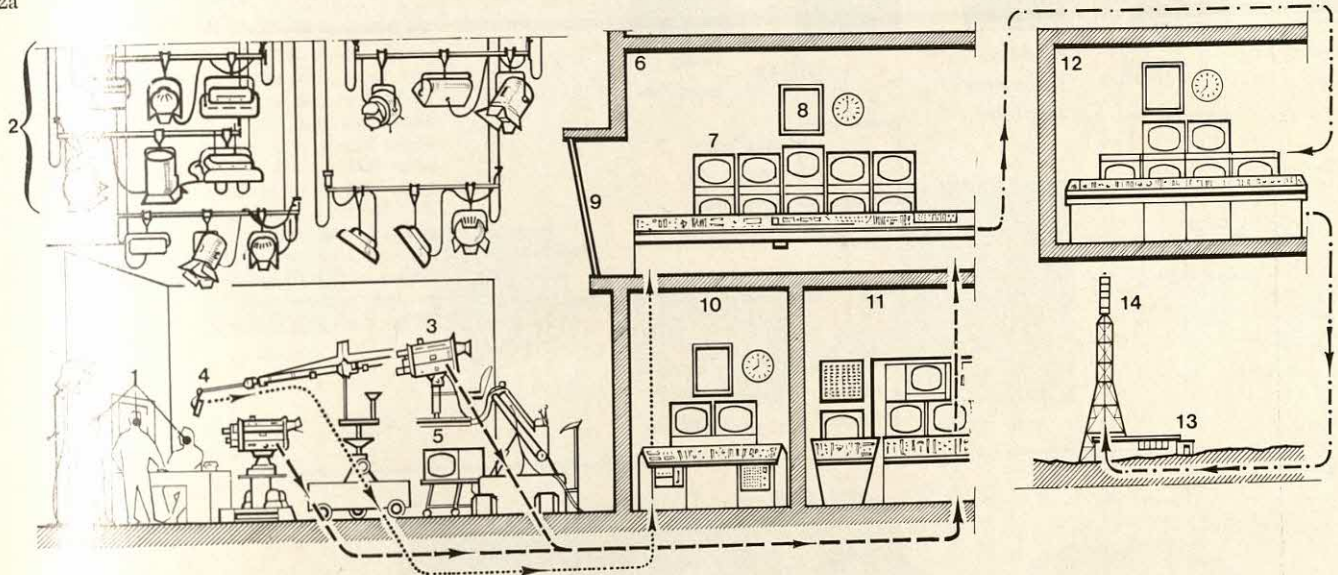
In general, television and radio transmissions are similar as to the generation, modulation, amplification, reception, and reproduction of the carrier wave. However, the criteria for the generation and the conversion on reception of video signals—those derived from an image—are substantially different from those of audio signals. Video transmission is based, as stated, on the breaking down into numerous dots—or scanning—of the image to be transmitted. But since the resulting picture must be transmitted without a flicker, perfect synchronization is necessary between the television camera, which performs the scanning operation in transmission, and the picture tube, which reassembles the picture on reception. No more than one ten-millionth of a second of variation between the two is permissible. Such synchronization can be



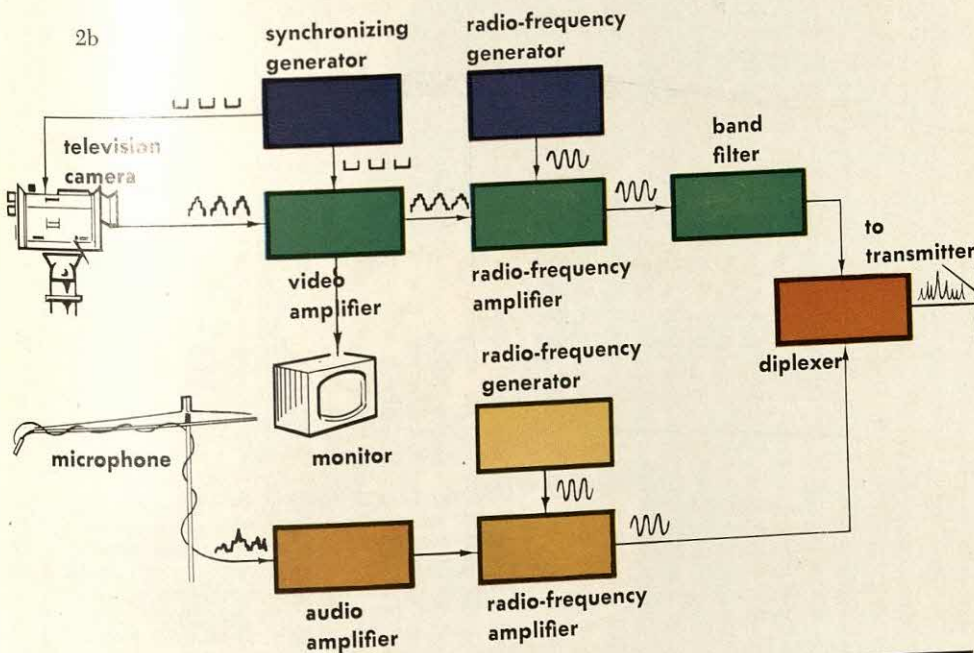
THE SCANNING OF THE IMAGE—The first concept for long-distance transmission of pictures in motion was developed toward the end of the nineteenth century by the German inventor Paul Gottlieb Nipkow, who devised the scanning disk (Illustration 1a)—a rotating disk with holes arranged in spiral formation. Through these holes the image of the subject to be transmitted was scanned, and the light from each individual dot was picked up by a photocell and converted into an electric signal.

The same concept is the basis of modern television transmission, in which the pictures (Illustration 1b) consist of a sequence of dots of varying brightness arranged in horizontal lines. The electric signals are formed in a different manner, however. With the image orthicon (Illustration 1c), the optical system concentrates the light on a photosensitive cathode; the cathode emits electrons in a quantity, point for point, proportionate to the amount of light received. The electrons are projected in a straight line toward a target that becomes electrostatically charged, forming an electric image equivalent to the original light image. The target is scanned by an electron gun with a beam that moves from left to right and from top to bottom, scanning the accumulated electrical charges and so modulated that its intensity varies in proportion to these charges. The return beam, which is picked up by the electron gun, thus has an instant-by-instant intensity proportionate to the charge deposited and, therefore, to the subject televised. The video signal thus composed is then amplified within the pickup tube to allow for further processing of the signal before transmission.

2a



2b

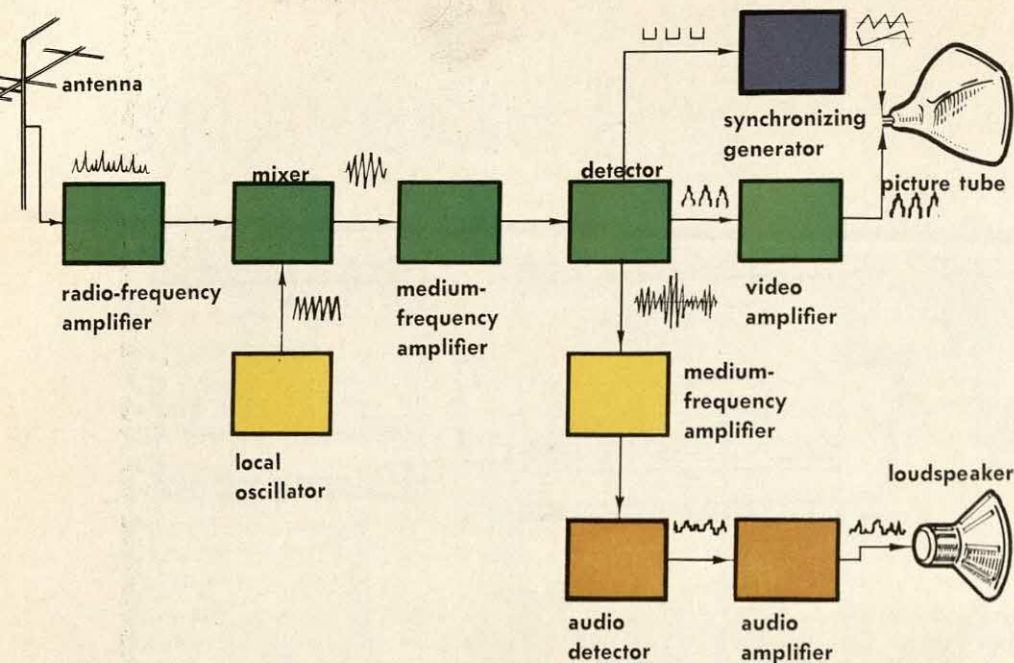


A TELEVISION TRANSMISSION SYSTEM—In a television studio (Illustration 2a) the persons or scene 1 to be televised are adequately lighted with various groups of lighting equipment 2. They are surrounded by television cameras 3; the microphone boom 4 is maneuvered near the performers from above, out of the line of vision. The picture being transmitted is checked in the studio on a monitor 5. The director controls all operations from a control booth 6, also equipped with monitors 7 on which he can see the pictures taken by each of the television cameras and can thus decide which ones to transmit at any given moment. Sounds are received over a control speaker 8, and the window overlooking the set 9 acts as an acoustical baffle. In separate sound-control 10 and video-control 11 areas, the sound and picture elements are adjusted so that their intensity and technical characteristics meet the requirements of the transmission. Both elements then pass through a central control booth 12, from which the signals are sent to the transmission center 13 to be broadcast from an antenna 14 or through a coaxial cable or radio relay to another transmitter in the network.

The electrical diagram of a television transmission system (Illustration 2b) begins with the camera and the microphone, which collect video and audio signals. A synchronizing generator regulates the line-scanning beam in the camera and simultaneously sends signals to the video amplifier, where they join the signals arriving from the camera. Both audio and video signals are modulated in their respective frequencies and then united into a single signal through the use of an electronic device known as a diplexer. The final power amplification takes place at the transmitter, at which point the signal is ready to be broadcast.

obtained only by the generation of special signals that regulate the scanning of the camera and are transmitted simultaneously with the video signals so that they may control the scanning of the picture tube as well. The synchronizing

signals control the timing of the currents that cause the scanning spot of the picture tube to be deflected across the viewing screen; this is done in the standard scanning pattern and in synchronization with the camera.

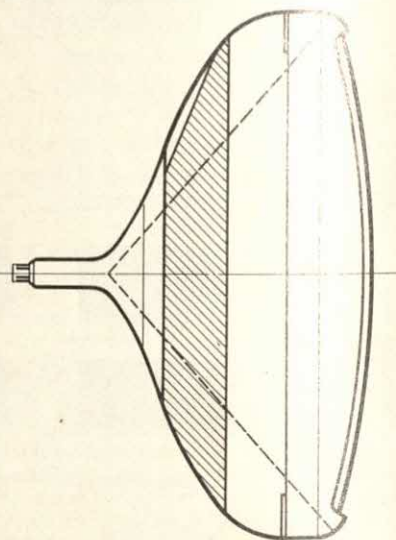
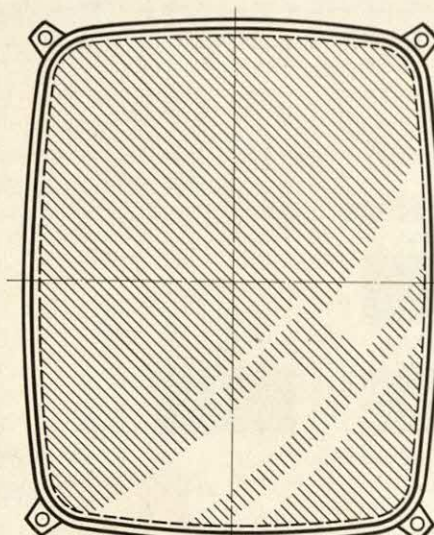
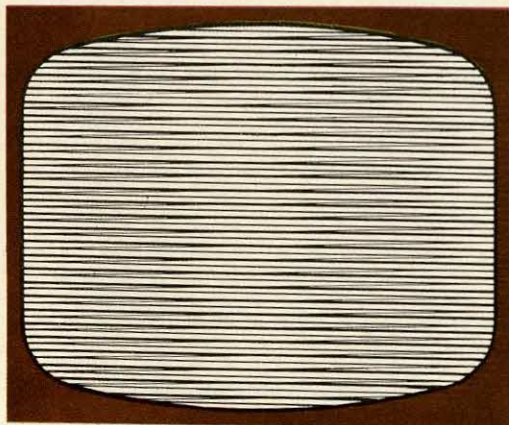


A TELEVISION RECEIVING SYSTEM—The signal broadcast by the transmitter is picked up by the antenna of the receiver and sent first to a radio-frequency amplifier connected with the channel-selection switch. As with radio receivers, a local oscillator produces an intermediate frequency that passes into a mixer, where the three elements of the original signal, as received, are separated. The audio signal is amplified for the last time and then detected, as in a radio receiver. The video signal, after detection, needs only to be amplified before reaching the picture-tube grid. The synchronizing signals are sent to the synchronizing generator, which has essentially two circuits, one for horizontal deflection and the other for vertical deflection. These circuits regulate the coils of the neck of the picture tube to guide the electron beam onto the screen.

4

b

a



THE PICTURE TUBE—A standard television picture in the United States is composed at the rate of 30 frames per second, each frame consisting of 525 horizontal lines. If scanning took place simply from left to right and from top to bottom, a flicker would result because of the difference in brightness between the various dots. Therefore a system of interlaced scanning (Illustration 4a) is required for both transmission and reception.

The scene is scanned, not in one uninterrupted phase, but in two phases. In one sixtieth of a second, the electron beam, starting from the center top, scans all the odd-numbered lines; then, in the next one sixtieth of a second, it begins to scan once more at the upper left corner and scans all the even-numbered lines; thus a picture of uniform brightness is obtained. The beam is deflected by a sawtooth voltage generated by local circuits, the frequencies of which are controlled by synchronizing signals from the transmitter. The voltage rises linearly, gradually deflecting the electron beam; a rapid reduction in voltage then brings the beam back to the beginning—on the left for horizontal deflection, at the

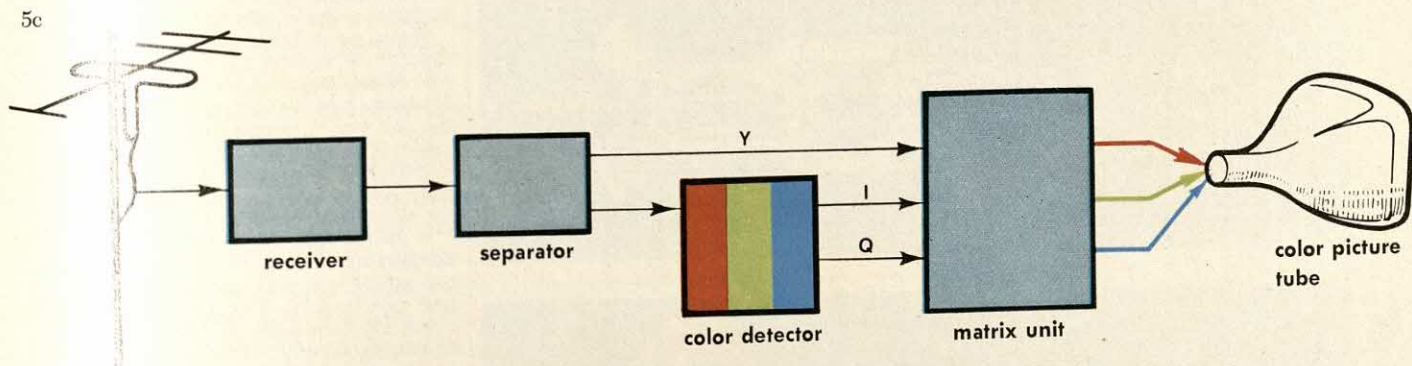
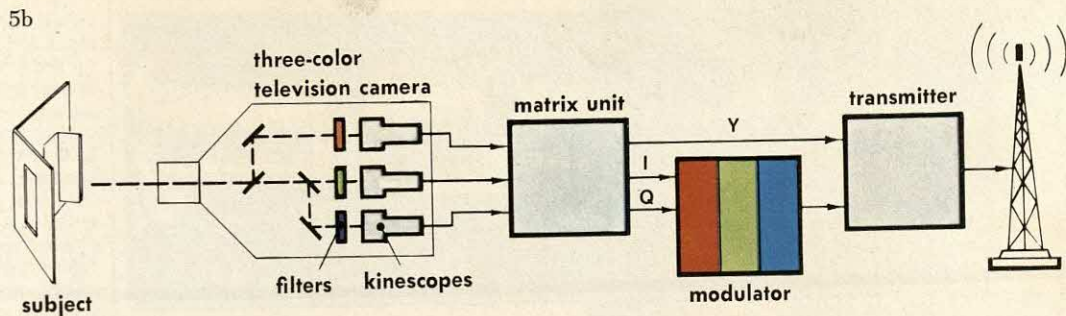
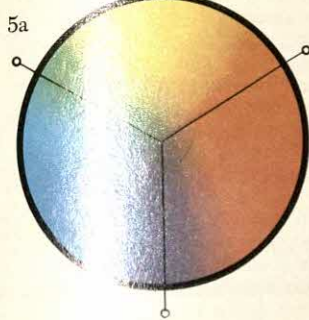
top for vertical deflection. This return to the beginning is called "return time" or "cancellation" (so called because, while the video signal is thus blocked, traces of the electronic beam are kept off the picture screen).

The picture tube (Illustration 4b) is a vacuum tube, the interior front surface of which is covered with a phosphor coating that produces light when bombarded with electrons. At the other end is a neck ending with an electron gun that emits electrons. The intensity of their flow is controlled by a grid on which the video signals are so focused that they are modulated instant by instant in proportion to the degree of brightness that appears in the picture. The electrons are propelled against the inner surface of the front of the picture tube after having been accelerated because of the power differential between the electron gun (negative cathode) and the walls of the tube. The beam, leaving the electron gun with modulated intensity, is deflected by high-voltage electromagnetic coils or electrodes so as to strike the screen in proper sequence. This result is achieved by bringing sawtooth voltage to the coils or

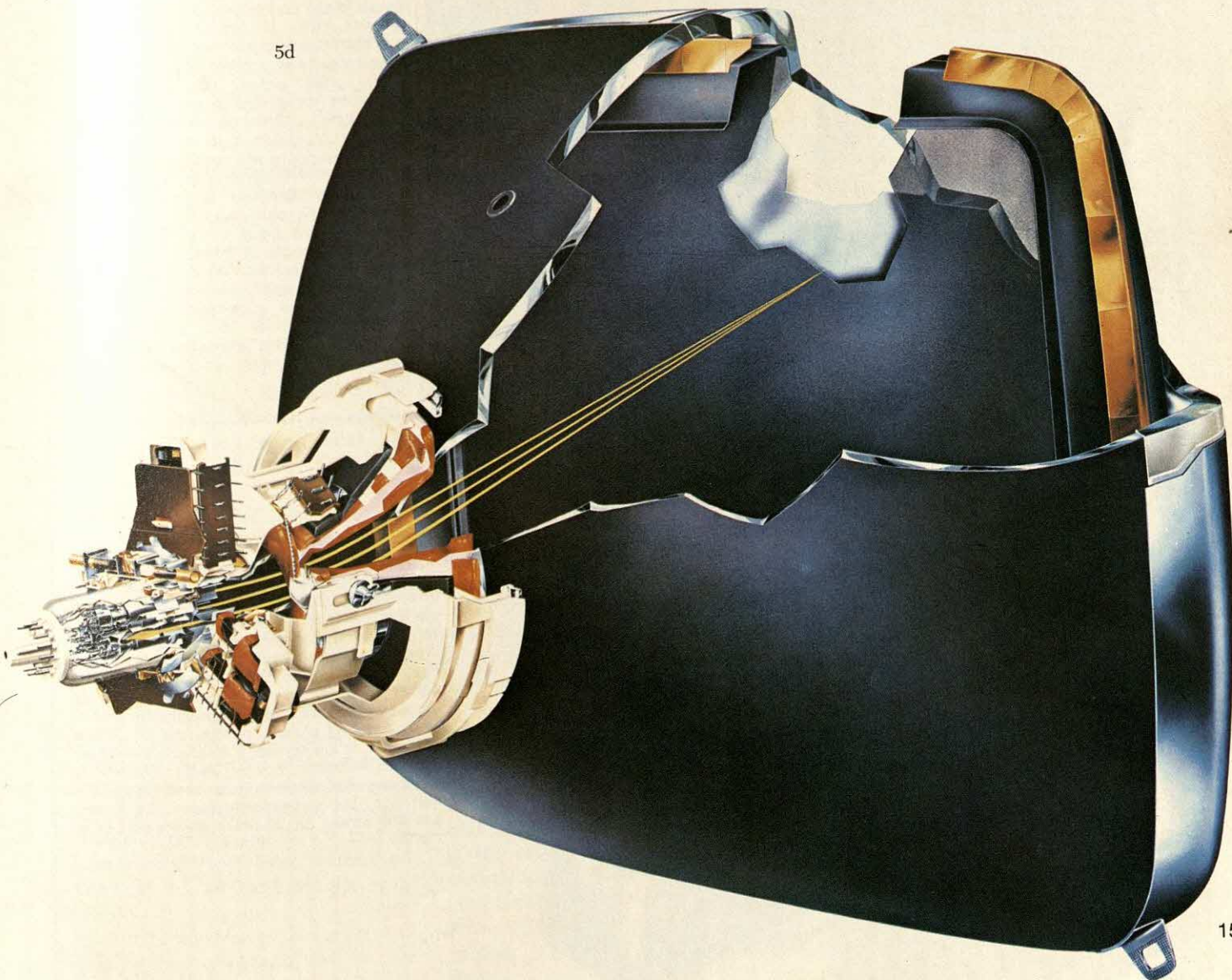
electrodes (of horizontal or vertical deflection), generated by local circuits and synchronized by signals received from the antenna.

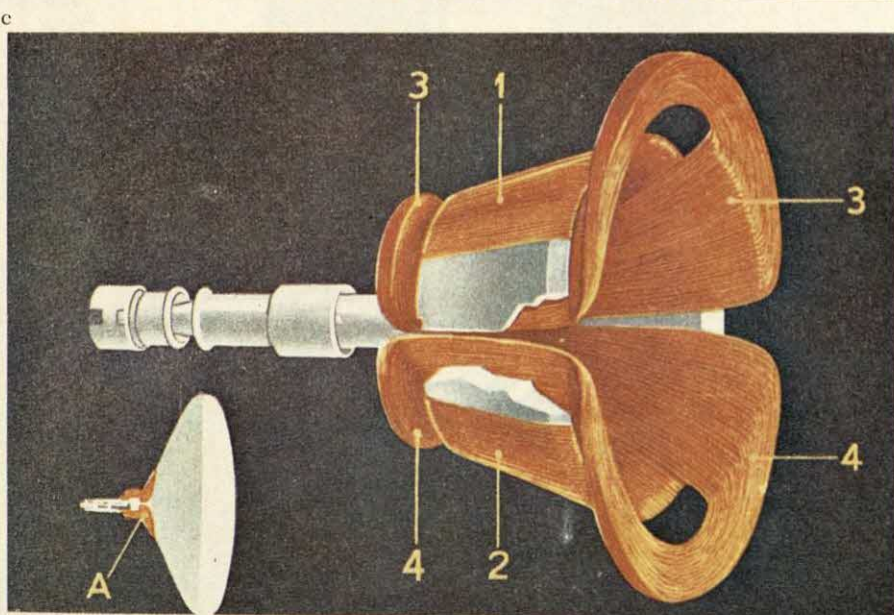
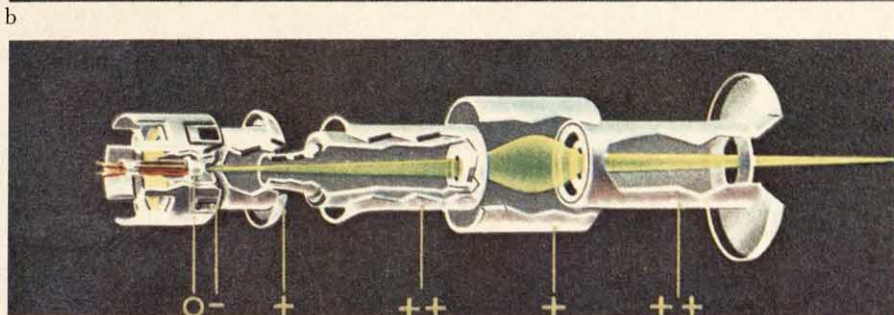
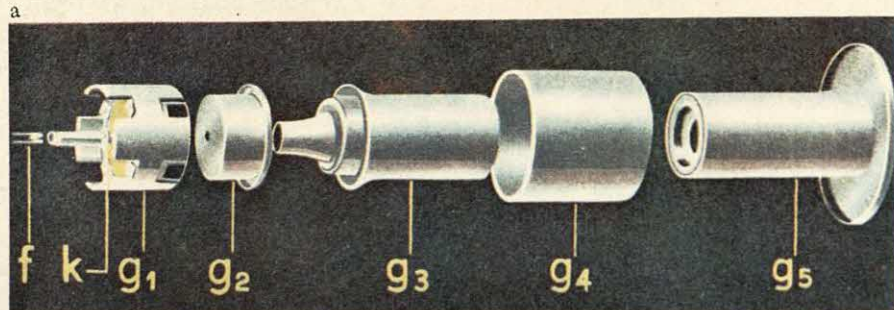
COLOR TELEVISION—Color television is based on the principle—widely applied in other fields of technology—that any color can be produced through the combination of three primary colors (Illustration 5a). In mixing pigments the primary colors are red, yellow, and blue; but in television, which involves the mixing of light, the primary colors are red, green, and blue. A transmitted color television signal will, therefore, be a combination of individual signals for each of these colors, synchronized with the audio signals.

With such a system, however, there is a basic problem of incompatibility: the incapacity of a black-and-white receiver to pick up color broadcasts. To avoid this problem, the signal must be modified. The color television camera (Illustration 5b) comprises three tubes (kinescopes) that receive images through three filters in a way that causes their signals to correspond to images in each of the primary colors. A special circuit, known as a matrix



5d



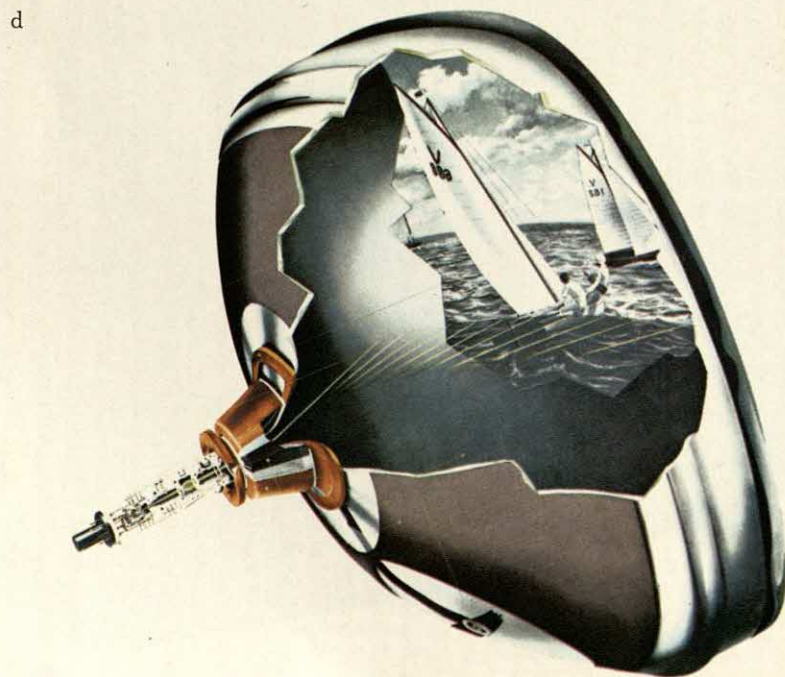


circuit, then processes these signals, producing a luminance signal Y corresponding only to the proportions of light and dark in the image; this signal produces a black-and-white picture on a noncolor television set. Two other signals, known as chrominance signals I , Q , furnish the additional information that specifies the color characteristics of each individual dot regardless of the required intensity of that color—in other words, the chrominance signals control the proportions rather than the amounts of two of the primary colors, and whatever proportion remains of the total must be that of the third color. (For example, if the two signals indicate 20 percent red and 50 percent blue, the green must account for the remaining 30 percent.)

These percentage values do not indicate whether the color in question should be weak or intense, bright or dark; such information is furnished by the luminance signal. The matrix unit also furnishes the chrominance signals, which are modulated to obtain a single color signal. This signal is sent to the transmitter along with the luminance signal and the synchronizing signals.

In the receiver (Illustration 5c) the operations are carried out in reverse, and the three original color signals are passed to the picture tube in color. The synchronizing signals in this case are especially complex, inasmuch as they must carry all the information needed to reproduce exactly the video signal in their proper place on the screen. Various television systems differ in the way the video and synchronizing signals are formed, but they follow the general principles described here.

The color picture tube (Illustration 5d) comprises three sets of phosphors that produce light in three colors corresponding to the filters inside the color television cameras. These phosphors are bonded to the glass in microscopic circles arranged with great precision in a triangular formation. Near the tube near the phosphors is a shadow mask containing tiny holes corresponding to each phosphor triangle of three colors. The three video signals are sent through the three electron guns, arranged in a triangular formation. The beam from each electron gun passes through the proper hole, which acts as a sight, and reaches without interference only the phosphor circles of the corresponding color.



THE SYSTEM PRODUCING THE BEAM—The electron gun of a picture tube is constructed in a much more complex manner than a simple oscilloscope. Illustration 6a shows the various electrodes that compose the gun. In Illustration 6b the electrodes are shown connected from left to right, with progressively higher voltages that serve to accelerate and focus the electron beam (green). To obtain an undistorted picture, despite the closeness of the gun to the screen, a magnetic deflection system (Illustration 6c) is needed. Illustration 6d shows the relationship between the electron gun, the deflection system, the beam, and the screen on which is shown part of a picture.

BIOGRAPHY

men of science—
inquiring and dedicated

The illusion persists among nonscientists that the world of science is, indeed, a world apart and that its cool denizens are, likewise, not of this world. Yet, science is a human endeavor. Scientific developments result from work done by inquiring men, and scientific progress is built up on information passed from man to man through the centuries. One man has a theory, another verifies it experimentally, generally using equipment invented by still other men. Thus, the perusal of an encyclopaedia of science is unsatisfying without a glimpse of the men behind the progress.

Something akin to science began in Egypt and Mesopotamia dozens of centuries ago when the learned men began to accumulate and write down what preliminary man had observed about time-keeping, healing, smelting, and building. No comparable advance was made for 3,000 years. Then the Greeks began to look for explanations of the world as they saw it. Their theories, often based on unground data, prevailed for 22 centuries; Western scientists did little more than enlarge on Greek theories. Gradually, men of science began to see inconsistencies in the time-honored ideas; and modern science—founded on observation, logical reasoning, and experimental proof—began. It is now only about 300 years old.

Today the world at large is acutely conscious of science. The public is informed immediately of such stunning breakthroughs as the discovery of DNA, the master molecule of life; the transplantation of a human heart; the landing of man on the moon; and a new method for seeing a single atom.

Small wonder that modern man is engulfed by scientific achievements when an estimated 90 percent of the scientists and engineers of all time are living and working now. Another of the twentieth century's staggering statistics is that recorded scientific knowledge doubled between 1948 and 1960 and doubled again by 1970.

Sometimes new discoveries must wait for new instruments. Such was the case

in 1970 when the British-born U.S. scientist Albert V. Crewe announced the development of a new kind of electron microscope that could "see" a single atom. The Crewe microscope had important implications for molecular biologists; now, perhaps, they might be able to read the genetic code along a strand of DNA and learn how a life is "programmed."

It has been noted that the discovery of the helical structure of the DNA molecule traces back directly to Wilhelm Conrad Röntgen's discovery of the x-ray in 1895. In a century when the existence of infrared and ultraviolet radiations had barely been revealed, the discovery of a radiation that could render the human body transparent to the eye naturally caught the public fancy—and caused some alarm: in London, England, a firm advertised an "x-ray proof" brand of underclothing.

Scientists, themselves, have had more serious concerns with what they have wrought. The German physicist Max Planck, who discovered the composition of energy, said in 1942, "Unless the inevitable, irresistible progress of science is accompanied by progress in civilization and moral awareness, mankind will rapidly approach self-destruction." The Danish physicist Niels Bohr, who developed the first consistent explanation of atomic structure, was only one of many scientists who worked tirelessly after World War II on behalf of the peaceful uses of atomic energy.

Through the years, scientists have met with ridicule, political harassment, and failure resulting from miscalculations or the clinging to time-honored dogmas. They have had to search and research.

The following pages represent the beginning of a two-volume biographical work. Volumes 19 and 20 of the *Illustrated World of Science Encyclopedia* continue this alphabetical arrangement of the names of more than 500 major world scientists, including, among many others, every Hall of Fame and Nobel Prize winner in the various fields of science.



ABEL, NIELS HENRIK (1802–1829)

In his brief but brilliant career Niels Abel addressed himself successfully to problems that had been baffling mathematicians for years. In mathematical analysis, in particular, his colleagues had been concerned with logarithms and other “transcendental functions”—those that could not be solved with a finite number of mathematical operations. Before Abel each function was considered as a separate case or problem. Abel, however, introduced the idea of a class of functions (emphasizing the general rather than the particular). He also made important contributions in the area of algebraic calculation.

Abel was born on August 5 at Finnøy, Norway. His father was a Protestant pastor. From his parents he derived peace of mind, and optimism, qualities that helped him greatly in a life of poverty and discouragement. He spent his childhood at Gierrenstadt, where he first went to school. Later he went to the cathedral school, where his teacher was B. M. Holmboe, a keen mathematician who became his mentor and later edited his work.

When he was sixteen years old, Abel began to read the works of the great mathematicians. He was already capable of understanding the work of Newton and Euler, and soon he was in a position to even criticize the works of the masters. Above all, he realized that many of the demonstrations of famous theorems were imperfect from more than one point of view, and that if he were to undertake a revision of mathematics he could even invalidate them. One of his first works was a demonstration that the binomial theorem of Newton was unacceptable. In 1820 Abel's father died at the age of forty-eight, and the young man found himself with a large family that he had to support.

Holmboe, who was convinced, and not without reason, that he had discovered the greatest mathematician of all time, tried to help Abel by finding him tutoring jobs. In the meantime, Abel's devotion to study caused him to neglect his health, and he contracted tuberculosis.

Among the various mathematical problems that he had determined to try to solve was that of algebraic equations.

Mathematicians in antiquity had learned to solve equations of the first and second degrees, and during the Renaissance they had succeeded in solving those of the third, and later of the fourth. The formula for these solutions becomes progressively more difficult with the higher degrees, so much so that mathematicians prefer to use approximate methods for

solving equations of the fourth and even of the third degree. No one had yet succeeded in finding a formula for solving equations of the quintic, or fifth degree.

Abel tackled this problem, however, and thought that he had reached a solution. He sent it to a Danish mathematician, who read it without realizing that it was wrong. Later Abel corrected it by



MÉMOIRE

SUR UNE PROPRIÉTÉ GÉNÉRALE D'UNE CLASSE TRÈS-ÉTENDUE

DE

FONCTIONS TRANSCENDANTES;

PAR M. N. H. ABEL,

NORWÉGIEN.

PRÉSENTÉ À L'ACADÉMIE LE 30 OCTOBRE 1826.

Les fonctions transcendentes considérées jusqu'à présent par les géomètres sont en très-petit nombre. Presque toute la théorie des fonctions transcendentes se réduit à celle des fonctions logarithmiques, exponentielles et circulaires, fonctions qui, dans le fond, ne forment qu'une seule espèce. Ce n'est que dans les derniers temps qu'on a aussi commencé à considérer quelques autres fonctions. Parmi celles-ci, les transcendentes elliptiques, dont M. Legendre a développé tant de propriétés remarquables et élégantes, tiennent le premier rang. L'auteur a considéré, dans le mémoire qu'il a l'honneur de présenter à l'Académie, une classe très-étendue de fonctions, savoir : toutes celles dont les dérivées peuvent être exprimées au moyen d'équations algébriques, dont tous les coefficients sont des fonctions rationnelles d'une même

The young Norwegian mathematician Niels Henrik Abel journeyed to the Paris Academy of Science (above) to present his paper *Memoir on a General Property of a Very Extensive Class of Transcendental Functions* in October

1826. It was not until 1841, however, that the work was published—years after Abel's untimely death. The paper had been entrusted to a French mathematician; he had passed it on to an assistant who lost it.

himself and sent it to the great Carl Gauss, who was surprised at seeing a letter from an unknown "concerning the solution of the equation of the fifth degree." Thinking the letter was from a crackpot, Gauss did not even bother to read the entire letter. If he had, he would have found that Abel had proved Gauss's own belief that a solution was actually impossible. Because of this unlucky circumstance, Abel remained unknown to Gauss.

Although the problem of algebraic equations was destined to be more fully elucidated by his contemporary Galois, Abel's method was shortly afterward used to tackle a far more important problem. His work states that before seeking an algebraic solution to equations, one must discover which are soluble equations and which are insoluble.

Abel's dream was a scientific tour of Europe, especially of France and Germany, where the finest mathematicians of the age lived. He hoped to bring his work to their attention. In 1825 he finally got substantial aid, a two-year grant, and he started south in September of that year.

In Berlin, Abel became friends with A. L. Crelle, an engineer by profession and an amateur mathematician who was also an editor. Crelle owed his fame to his review, the *Journal für die reine und angewandte Mathematik*, usually called *The Crelle* for short. The first issue consisted entirely of Abel's papers, all of a high level and on varied subjects.

Abel went to Paris in July 1826. In spite of his own well-disposed frame of mind, he found the French amiable but reserved.

Abel's basic work was published only after the most extraordinary vicissitudes. Not wanting to break off his stay in Europe, he entrusted the renowned Adrien-Marie Legendre of the Academy of Sciences with the publication of it. Legendre, however, who was seventy-four, found it difficult to read and gave it to his younger colleague Augustin-Louis Cauchy, who took it home and lost it. Only many years after Abel had died was it found again, thanks to the mathematician K. G. J. Jacobi, who had heard about it and forced Cauchy to locate it. When at last it was found and sent to the printer, the manuscript was lost be-

fore the first proofs were ready. *Memoir on a General Property of a Very Extensive Class of Transcendental Functions* did not appear until 1841.

Abel's work was concerned with the study of a problem involving transcendental functions. To understand the problem, consider the direct trigonometrical functions (sine, cosine, etc.); it is very easy to establish functional relationships between these. Then consider their opposites (arc sine, arc cosine, etc.). For these it is hard to find the analogous properties, and it is difficult to work back from these to the properties of the direct functions.

At the time when Abel was working on the functions that interested him, new functions were being discovered. For example, Legendre had found the elliptic integrals that enabled him to define the inverse functions of the so-called elliptical functions, but after forty years he had not yet thought of inverting the integrals in order to find functions that were easier to work with. Abel, however, discovered a system of working in a general way on a vast number of transcendental functions; and choosing between direct and inverse functions, he gave an example in which it was easier to find the properties. Abel's theorem is that there is a finite number of independent integrals in an algebraic function.

If Abel's childhood, youth, and early studies were fraught with hardship, his last years were scarcely easier. He returned to his impoverished homeland and saw his family and his fiancée again. His hopes of a professorship at the university came to nothing because the position had been given to Holmboe. Critically ill with tuberculosis, Abel was concerned about the future of his fiancée and urged his best friend to marry her after Abel's death. Meanwhile, Crelle was still working to get a professorship for Abel at Berlin. Two days after Abel's death a letter arrived confirming his appointment at Berlin.

ADRIAN, EDGAR DOUGLAS, 1ST BARON OF CAMBRIDGE (1889–)

In 1932 Edgar Douglas Adrian and Sir Charles Scott Sherrington, British physiologists, won the Nobel Prize in medicine or physiology for their discoveries re-

garding the neuron and nerve impulses. (See Sir Charles Scott Sherrington.)

Early in his career Adrian was performing brilliant research on nerve impulses. In his electrophysiology work Adrian successfully used a relatively new technique—sound amplifying. Adrian, however, was not the first to use a radio-type amplifier in connection with nerve impulses; this distinction belongs to Gasser, who with his colleague Erlanger won the 1944 Nobel Prize in medicine or physiology. (See Joseph Erlanger; Herbert Spencer Gasser.)

In the 1920s Adrian and his colleague Dr. Y. Zotterman divided the muscle of a frog until it contained just one sense organ. They stretched and pulled the muscle to stimulate the nerve impulses passing through this sense organ. The next step was to amplify the sound of the impulses and to record the sound. By such means they could study nerve impulses precisely.

Adrian found that more pronounced stretching of the muscle (an increasing stimulus) brought about more frequent nerve impulses. Previously scientists had thought that the impulses came at a single rapid rate, more or less uniform, regardless of the stimulus.

Another of Adrian's discoveries was that sense organs can and do adjust to a prolonged change in stimulus. A stronger stimulus will quicken the nerve impulses initially, but after a period of time that same stimulus will lose some of its power and will have a less pronounced effect on the nerve impulses.

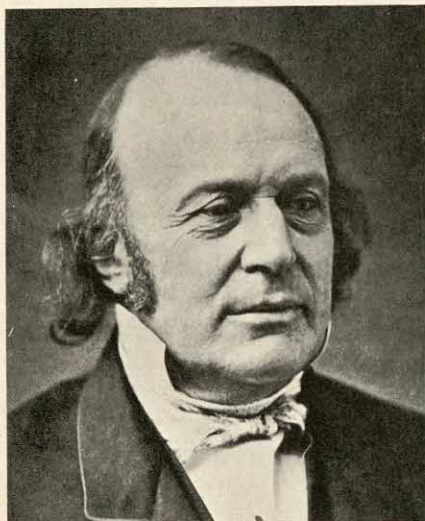
After 1934 Adrian studied electrical activity in the brain. His work provided new leads on the treatment of epilepsy.

Adrian was born in London and educated at Westminster School and Trinity College, Cambridge. He received his medical degree in 1915. He had a long distinguished association with Trinity College, beginning as a fellow in 1913, advancing to professor of the Royal Society, professor of physiology, and finally Master of Trinity (1951–1965). Adrian was the ninth fellow of Trinity to receive a Nobel prize.

In 1942 he was awarded the prestigious Order of Merit. From 1950 to 1955 he was president of the Royal Society. He was elevated to the peerage in 1955, becoming the first baron of Cambridge.

AGASSIZ, JEAN LOUIS RODOLPHE
(1807–1873)

The scientific career of Louis Agassiz ranged from the systematic study of ancient life to the passionate contemporary debate over Charles Darwin's theory of evolution. Agassiz was a naturalist, a geologist, and an educator. He made major contributions to the literature of fossil fishes and of glaciers; his fieldwork and his teaching methods were very influential.



Agassiz was born in Môtier, Switzerland, the son of a Protestant clergyman. Young Louis studied at the universities of Zürich, Heidelberg, and Munich; he then went on to earn advanced degrees: a doctor of philosophy at Erlangen and a doctor of medicine at Munich.

At the age of twenty-two he published his first work, a study of the fishes of Brazil begun by a colleague who died before he could complete the work. He published additional volumes of his own study; through the work of Agassiz the number of known fossil fishes was raised to nearly 1,000. He made an important contribution to the study of ancient fish forms and branched out to study other forms of extinct marine life. His work was credited with stimulating the study of ancient life and ancient forms in general.

In 1836 Agassiz began a field study of glaciers. He observed glaciers in the Jura Mountains, noting that rocks had accumulated at the edges and, moreover, that many rocks were grooved in a way that

suggested the glacier had made the grooves by passing over the rocks. Similarly, grooved rocks were also found at a considerable distance from any glacier. In order to test the theory that glaciers moved, he built a hut on a glacier and used stakes driven into the ground as a line of measurement. The glacier moved measurably.

Agassiz concluded that glaciers had once covered Switzerland and that "Great sheets of ice, resembling those now existing in Greenland, once covered all the countries in which unstratified gravel (boulder drift) is found." Before Agassiz, a few scientists had theorized that glaciers once existed on a larger scale; after Agassiz the concept of an Ice Age was expanded to include many such ages in different times and places.

He was invited to lecture in the United States in 1846. He became professor of natural history at Harvard College in 1848 and stayed there for the rest of his life, becoming a U.S. citizen in 1861. He constantly stressed the importance of fieldwork over textbooks; his methods revolutionized the teaching of natural history at Harvard. He was the first director of the Museum of Comparative Zoology at Harvard, sometimes called the Agassiz Museum.

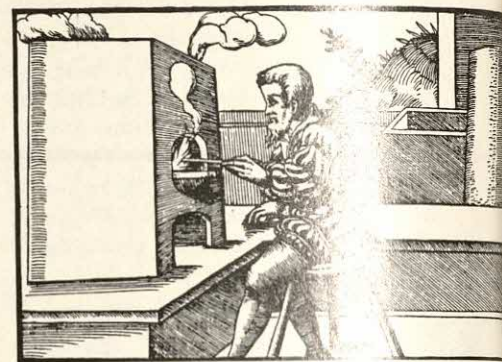
Agassiz was generally considered the most important U.S. scientist to oppose the evolutionary theory of Darwin. (See Charles Robert Darwin.) He based this opposition on his own studies of fossil fishes. Some advanced and well-developed species of fish appeared to predate some simpler species; Agassiz could not reconcile this with the idea of the continuous evolution of species.

His second wife, Elizabeth Cabot Cary, was a noted educator and a founder of Radcliffe College. His son Alexander became a marine biologist and a mining engineer.

AGRICOLA, GEORGIUS (1494–1555)

"The Father of Mineralogy," Agricola, was a German physician and scholar who made contributions to a number of scientific fields—including medicine, chemistry, and mathematics. Agricola's career as a physician in mining areas led to his interest in systematic mineralogy.

He was born Georg Bauer in Glauchau,



In a drawing typical of many in Agricola's *De Re Metallica* (1556), an assayer tests metal in a rectangular assay furnace. Many operations of fire assaying are still used in industry for determining the precious-metal content of large ore samples.

Saxony; later in life he decided to use the Latin form of his name, and he also wrote his books in Latin. After graduating from the University of Leipzig in 1518, he went to Italy to study medicine and received his medical degree from the University of Ferrara.

In 1527 Agricola began his medical practice in the mining town of Joachimsthal in Bohemia. In 1531 he became the town physician of Chemnitz, an even larger mining center. His observations of Saxon mining practices were careful and thorough; he was the first writer on the subject of mineralogy to use observation rather than speculation as a basis for his work.

His most important book, *De Re Metallica*, was published posthumously in 1556. It was the first mineralogy text and is still considered a classic explanation of mineralogy; it contains many useful illustrations. As a young engineer, Herbert C. Hoover, with the aid of his wife, translated the book into English.

In another book, *De Natura Fossilium*, Agricola outlined a new classification of minerals based on their physical properties. He also described a number of new minerals.

ALBERTUS MAGNUS (1200?–1280)

Saint Albertus Magnus, or Albert the Great, was a scholastic philosopher, theologian, and scientist. Probably his greatest contribution to science was that he defended Aristotle's science teachings against attacks by regressive medieval theologians. Albert was called *doctor*

universals for the broad range of his knowledge.

Albert was born in Swabia, a German duchy of that era. He joined the Dominican order in 1223. He taught at various German schools and at the University of Paris. In Cologne one of his students was Thomas Aquinas, who was to become a renowned philosopher and theologian. After his retirement Albert spent most of his time in Cologne pursuing his scholarly and scientific interests.

The foremost naturalist of his day, Albert observed and described many plants and animals, some of which had never been listed. He stressed the importance of observation, in botany particularly.

He also performed a number of alchemical experiments. From his own observations and from his studies, he wrote *De Mineralibus*, describing 95 minerals and a number of chemical substances.

Albert was the only medieval philosopher to comment on all the works of Aristotle. He was also familiar with the works of Arab thinkers who had refined or expanded some of Aristotle's concepts.

Although Albert accepted some of Aristotle's errors—for example, identifying whales with fishes—he corrected others. The fact remains, however, that Albert did almost no original thinking or theorizing. He took Aristotle for his chief inspiration, but he was also influenced by the neo-Platonists and other mystical thinkers. Nonetheless, his staunch defense of science in the Middle Ages earned him a permanent place in history. (See Aristotle.)

ALDER, KURT (1902–1958)

The German chemist Kurt Alder worked as a research assistant to the distinguished chemist Otto Diels; together they discovered the diene synthesis, a singular accomplishment in the annals of modern organic chemistry. For their discovery Diels and Alder shared the 1950 Nobel Prize for chemistry. (See Otto Paul Hermann Diels.)

A diene is a chemical compound containing two double bonds; the diene synthesis is a method of making organic chemicals by combining dienes with other

chemical substances. In 1928 Diels and Alder published their historic paper on the synthesis. They described the reaction when they combined dienes with quinones. Others had performed such a combination, but Diels and Alder were the first to show experimental proof of the synthesis. They also were the first to tell how the synthesis could be used on a variety of ring compounds.

The diene synthesis is valuable precisely because it has so many applications. The synthesis can be used to make a great number of organic chemicals. Other chemists applauded the almost simple genius of Diels and Alder; the diene synthesis requires no unusual temperatures, no tricky techniques. There are important applications of the diene synthesis in the manufacture of synthetics. When butadiene is combined with another substance, for example, one of the products is synthetic rubber.

Alder was born in Königshütte, Germany (now Chorzow, Poland). He graduated from the University of Berlin with a degree in chemistry and then went on to receive a doctorate from Kiel in 1926. Eight years later, in 1934, he became a professor at Kiel. After two years there, he was employed by the research laboratories of I. G. Farben. In 1940 he became professor of chemistry and director of the chemical institute at the University of Cologne. During World War II he was engaged in research on the industrial applications of the diene synthesis.

ALVAREZ, LUIS WALTER (1911–)

The U.S. physicist Luis W. Alvarez who is a professor at the University of California's Lawrence Radiation Laboratory, Berkeley, received the Nobel Prize for physics in 1968. He was cited for "decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using a hydrogen bubble chamber and data analysis." During the course of his work with subatomic particles he developed ever larger liquid hydrogen bubble chambers, found methods of recording data through stereophotography, and introduced faster data analysis by computer. His work was largely



Scala New York/Florence

responsible for the increase in the list of known subatomic particles from about 30 when he began his work to more than 100 by 1970.

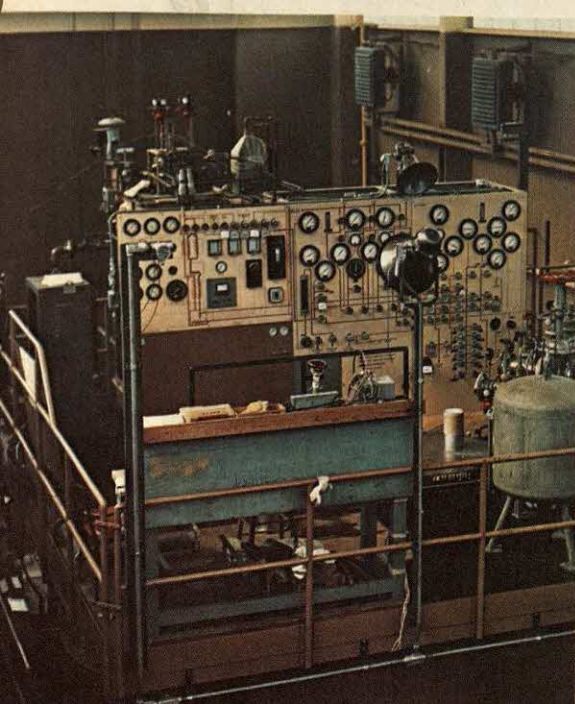
Alvarez and his colleagues announced in 1960 the discovery of the first three extremely short-lived particles, or resonances. Nearly all the new short-lived particles have been found in hydrogen bubble chambers.

Though most famous for the work cited, Alvarez also developed a way to x-ray the Egyptian pyramids, floated spark chambers into the upper atmosphere, produced nuclear reactions without uranium, invented a color television system, and discovered radioactive helium.

Luis Alvarez was born in San Francisco, California, the son of a famous physician. He took degrees at the University of Chicago in 1932, 1934, and 1936. He then joined the faculty of the University of California. During World War II he did research in radar and invented microwave beacons. He was involved with the development of the first atomic bombs and attended the first atomic explosion in New Mexico in 1945. Later, he flew over Hiroshima, Japan, as

A large hydrogen bubble chamber, below, is in use at the Lawrence Radiation Laboratory of the University of California, Berkeley, where Nobel Prize winner Luis W. Alvarez has made important contributions to elementary particle physics. He developed stereophotography, a technique for photographing and analyzing the strings of bubbles left by particles as they pass through liquid hydrogen in the chamber.

Courtesy Lawrence Radiation Laboratory of the University of California, Berkeley



Courtesy Lawrence Radiation Laboratory of the University of California, Berkeley



a scientific observer. In 1947 he was elected a member of the National Academy of Sciences, and his other awards include the Collier Trophy, presented in 1945 to honor him for the ground-controlled landing approach system he devised for airplanes during World War II, and the 1964 National Medal of Science. He is a fellow of the American Physics Society.

AMBARTSUMIAN, VIKTOR AMAZASPOVICH (1908—)

Since World War II, Ambartsumian has become internationally recognized for his studies of star formation and of the evolution of stars. He is a Soviet (Armenian) astrophysicist.

Examining stars in clusters, Ambartsumian and his colleague P. Kholopov concluded that the faint stars are young ones of unstable association—which they termed T-associations. (Later it was shown definitely that some of these T-associations were breaking up.) Some short-lived clusters were shown to be made up entirely of very young or faint stars.

From this work Ambartsumian concluded that stars arise in groups as a result of the disintegration of massive bodies that he called protostars. When a protostar disintegrates, some of its material scatters and becomes diffuse. This explains why clusters of young stars are surrounded by a dense gaseous mist.

Through his work with stars Ambartsumian arrived at a new theory of the

origin of the universe (cosmogony). The commonly accepted theory was based on condensation, or the process of becoming more complex or dense. This did not explain certain facts about the stars and the heavens, such as the disintegration of the protostars. Ambartsumian based his theory on rarefaction, or the process of becoming thinner or less dense.

In 1955 he disproved a commonly accepted theory about galaxy formation. The old idea was that any galaxy originated from the collision of two ordinary galaxies. Ambartsumian showed, however, that a radio galaxy could arise from a single ordinary galaxy as a result of an internal explosion.

Ambartsumian was born in 1908 in Tbilisi, Russia. He was graduated from Leningrad University in 1928 and completed a post-graduate course at the Main Astronomical Observatory at Pulkovo in 1931. For his contributions to astrophysics, he received an honorary doctor's degree from the Sorbonne in 1966.

From 1931 to 1946 he was successively a lecturer, professor, "protector," and "head" of astrophysics at Leningrad University. In 1947 he became director of the



Byurakan Astrophysical Observatory. He has held leadership positions in both the Armenian Academy of Sciences and the Academy of Sciences of the U.S.S.R.

His international awards include the Gold Medal of the British Royal Astronomical Society and the Catherine Wolfe Bruce Medal of the Astronomical Society of the Pacific. From 1948 to 1955 he served as vice-president of the International Astronomical Union. He was elected a foreign associate of the U.S. National Academy of Sciences in 1959.

AMPÈRE, ANDRÉ MARIE (1775–1836)

The ampere, a unit that measures the flow of an electric current, was named after André Marie Ampère, a French scientist. His theory of electromagnetism led the way to the modern scientific field of electrodynamics.

In 1820 the Danish scientist H. C. Oersted discovered that a magnetic needle of a compass is deflected by electric current. In a matter of days after hearing of this discovery, Ampère formulated his theoretical explanation of electromagnetism. He included mathematical formulas to substantiate his ideas on the flow of current.

Ampère invented the astatic needle, a forerunner of the galvanometer. He also wrote a treatise on the philosophy of science; in fact, he wrote on a wide variety of scientific subjects, including animal physiology.

He was born in the village of Polémieux, near Lyons, France. Beginning in 1799, he tutored in mathematics, chemistry, and language. In 1801 he became professor of physics and chemistry at Bourg and in 1809 was appointed professor of mathematics at the École Polytechnique in Paris. Five years later he

The Sorbonne, part of the University of Paris, is an internationally renowned center of learning. Ampère taught philosophy at the Sor-

bonne became a member of the prestigious Institut National. In 1824 Ampère became professor of physics at the Collège de France in Paris.



Ampère's personal life was dogged by tragedy. His father, Jean Jacques Ampère, was guillotined during the French Revolution in 1793. André's wife died in 1804, and most biographers note that he never fully recovered from her death. He married again in 1807, but the marriage failed after two years.

AMUNDSEN, ROALD (1872–1928)

The Norwegian explorer Roald Amundsen is a towering figure in the history of polar exploration. He discovered the South Pole, and that feat alone would qualify him for a place in history. In ad-

dition, he was the first man to navigate the Northwest Passage from the Atlantic Ocean to the Pacific, and he is considered the first to fly over the North Pole in a dirigible.

dition, he was the first man to navigate the Northwest Passage from the Atlantic Ocean to the Pacific, and he is considered the first to fly over the North Pole in a dirigible.

He was born in Borge, Norway, the son of a shipowner. He went to medical school for two years but dropped out to go to sea. At the age of 25 Amundsen became the first mate of the *Belgica*, a Belgian ship that explored Antarctica.

He started his own expedition in 1903 on the ship *Gjøa*, sailing in secret to avoid bill collectors. He was looking for the north magnetic pole. After making observations of the region for two years from a vantage point in Greenland, Amundsen concluded that the magnetic pole was not a fixed location. It was on this trip that Amundsen navigated the Northwest Passage, a feat that had baffled explorers for 300 years.

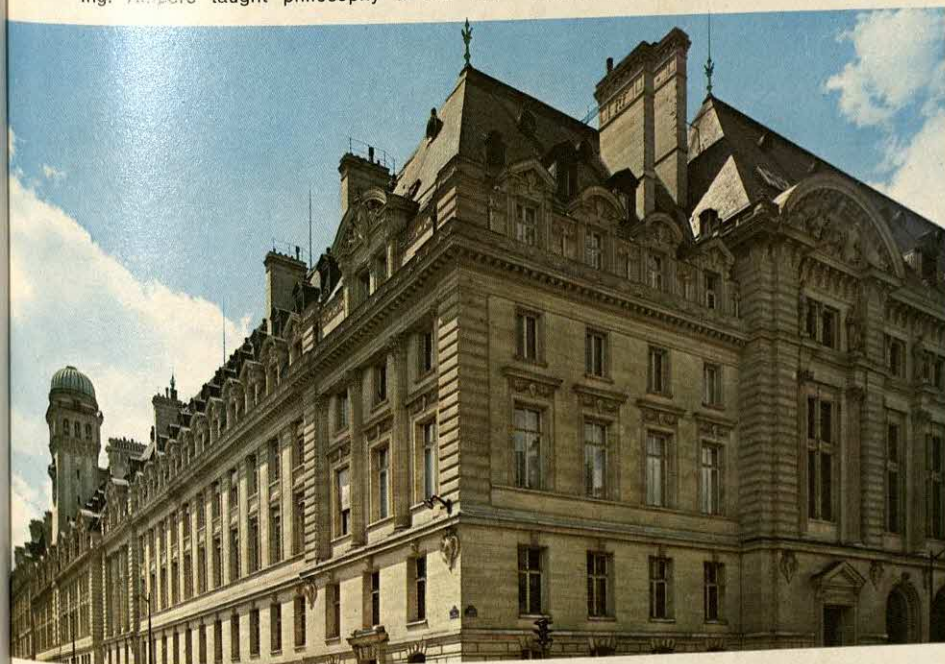


Setting forth on the ship *Fram*, Amundsen planned to drift across the North Pole. He heard, however, that Peary had already reached the pole. (See Robert Edwin Peary.) Amundsen therefore decided to look for the South Pole; he reached it December 14, 1911—only 35 days before the arrival of Robert F. Scott.

In 1918, in the *Maud*, Amundsen made an unsuccessful attempt to drift across the North Pole from Asia to North America. Two years later he made another attempt and was successful. On this trip he sailed through the Northeast Passage.

In May 1926 Amundsen flew over the North Pole in a dirigible piloted by Umberto Nobile of Italy. They made a long flight from Spitsbergen to Teller, Alaska. Later Amundsen became involved in a dispute over this flight, centering around whether he or Nobile should receive credit for the first.

On another journey in 1928 Nobile was lost over the Arctic. Amundsen set out in a small plane to search for him. Nobile was eventually found by someone else, but Amundsen's plane went down and Amundsen was killed.



Courtesy California Institute of Technology;
photograph, T. W. and M. A. Harvey

ANDERSON, CARL DAVID (1905–)

The 1936 Nobel Prize in physics was awarded to Carl David Anderson for discovering the positron. He shared the prize with Victor Franz Hess, whose discovery of the cosmic ray was instrumental in Anderson's work. (See Victor Francis Hess.)

Anderson designed a magnetic cloud chamber divided by a lead plate. The cosmic rays in the cloud chamber were, in effect, curved by the lead plate; this curve made it easier to study the properties of the particles that made up the cosmic rays. In 1932, while studying photographs of cosmic rays, Anderson found tracks that looked like those of an electron but were curved in the opposite direction. The tracks turned out to be those of an electron with a positive charge; thus Anderson coined the name positron as a contraction of positive electron.

In the 1930s the physicist Hideki Yukawa theorized the existence of an intermediate particle. This particle would act to bind together the protons and neutrons that form the nucleus of an atom. Anderson became involved with Yukawa's theories; in 1935 Anderson observed a new track with an unusual curve, less than that of an electron but



greater than that of a proton. He identified it as the intermediate particle discussed by Yukawa and called it the meson. Anderson's meson turned out to be very short-lived. Later the existence of more than one intermediate particle was confirmed, and Anderson's was renamed the mu-meson.

Anderson was born in New York City. He received his Ph.D. from the California Institute of Technology in 1930. He then began a long distinguished teaching career at Cal Tech and was appointed professor of physics in 1939.

The California Institute of Technology at Pasadena, where Anderson has long been associated, is a world renowned center of scientific research and training. The Norman Bridge

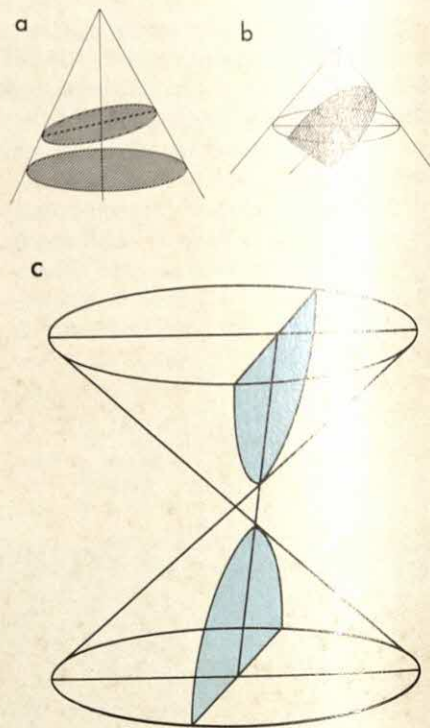
laboratory of physics stands near the tall library building that was named for the late Robert A. Millikan, the 1923 Nobel Laureate in physics.



Courtesy California Institute of Technology Photo

APOLLONIUS (third century B.C.)

Apollonius of Perga was a Greek mathematician who came to be known as "the Great Geometer." Flourishing about 50 years after Euclid, he was regarded as a pure geometer until the nineteenth century. Apollonius is particularly known for his eight-book treatise on "conic sections." Taking the cone as a solid, he identified and named three curves (which he called "sections") for the first time: ellipse (a), parabola (b), and hyperbola (c). For centuries these curves appeared to be interesting to a pure or academic mathematician, but they were thought



to have no practical applications. Around the year 1600, however, Johannes Kepler used the ellipse and the parabola to work out the orbits of planets and other heavenly bodies. (See Johannes Kepler.) Sir Isaac Newton later used Kepler's calculations in his studies that led to the theory of universal gravitation.

Little is known about the life of Apollonius. He was born in Perga, in the area that is modern-day Turkey. He was educated at the Museum. Apparently he was very familiar with the work of Euclid, but Apollonius made important contributions of his own to geometry. (See Euclid.)

THE ILLUSTRATED SCIENCE DICTIONARY

Aa to Arithmetic Unit

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PREFACE

The Illustrated Science Dictionary has been prepared to help young people and adults understand and use correctly the exacting language of today's science and technology. The dictionary will be particularly useful to the general reader who is confronted repeatedly with science words and terms in books, magazines, and newspapers. It will be essential to young people of all educational levels who are studying science in school.

The words defined and illustrated in the *Illustrated Science Dictionary* have been drawn from the specialized vocabularies of fourteen sciences. They were chosen by a group of scientists, science educators, and curriculum specialists representing all parts of the United States and Canada. Following the specialists' approval of the basic word list, a team of experts representing all the sciences defined the words as they are used in specific sciences. Then, to show the use of each word or term in context, an illustrative sentence was constructed that, in most cases, added to the meaning of the term.

Immediately following each entry is its pronunciation. Following the pronunciation of each word is an italic abbreviation which gives the part of speech of the word in the sense in which it is defined. If the word is used as a different part of speech in different sciences, this fact is indicated in the definitions.

In some cases the definition is a general one because the word or term is used in many sciences to express the same idea. In such definitions no particular science is indicated. In all other cases the words are defined in terms of their most common use in one or more specifically named sciences. Thus a word may have several different meanings, each related to a specific science or to a general scientific concept. If an entry has both specific and general definitions, those that apply to specific sciences are given first and the general definitions follow. "Grain" is an example of a word with a variety of meanings. This commonplace word is defined in terms of four sciences, in each of which it has a significantly different meaning.

KEY TO PRONUNCIATION

The diacritical marks are:

ə	banana, abut	j	job, gem
ə	preceding l, m, n as in battle	ŋ	sing
ə	electric	ō	bone
ər	further	ò	saw, all
a	mat	oi	coin
ā	day	th	thin
ä	cot, father	th	then
aü	now, out	ü	rule, fool
e	bet	ù	pull, wood
ē	beat	ue	German hübsch
i	tip	üe	French rue
ī	bite	yü	union
		zh	vision

¹ mark preceding the syllable with strongest stress.

² mark preceding a syllable with secondary stress.

The system of indicating pronunciation in these volumes is used by permission from Webster's *Third New International Dictionary*, copyright 1961 by G. & C. Merriam Co., Publishers of the Merriam-Webster Dictionaries.

A

aa \ 'ä-,ä\ *n.*

EARTH SCIENCE. A type of lava characterized by a rough clinker-like surface.

Several Hawaiian volcanoes have produced AA.

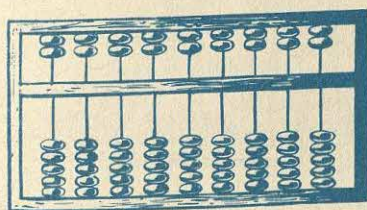


AA

abacus \ 'ab-ə-kəs\ *n.*

MATHEMATICS. An instrument used by early civilizations to perform mathematical computations and still in use in various parts of the world. It consists of a frame with rods on which counting beads can be moved up and down.

The ABACUS is one of the oldest counting devices.



ABACUS

abdomen \ 'ab-də-mən\ *n.*

1. **ANATOMY.** The part of a human or animal body that contains the stomach and intestines. 2. **ZOOLOGY.** A division of the bodies of most arthropods, such as insects and crustaceans.

The strong, thick muscles of the human ABDOMEN provide protection for the stomach and intestines.

abductor muscles \ ab-'dək-tər 'məs-əlz\

ANATOMY. Muscles that pull limbs away from the midline of the body.

Along with other arm and shoulder muscles, the ABDUCTOR MUSCLES of the arm are used in throwing a baseball.

aberration \,ab-ə-'rā-shən\ *n.*

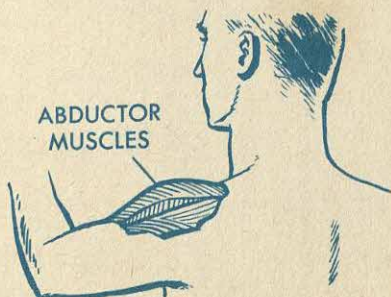
PHYSICS. The distortion in shape or color of an image as it is seen through a lens that does not bring light waves to an accurate focus or that does not refract all colors equally.

An ABERRATION in a telescopic lens can create rings of color around the image of a star.

abiogenetic \,ā-,bī-ō-jə-'net-ik\ *adj.*

BIOLOGY. Pertaining to the concept of spontaneous generation—the origination of living organisms from lifeless matter.

Pasteur and others proved that the ABIOGENETIC theory was not a valid explanation for the unexpected appearance of living things.



ABDUCTOR
MUSCLES

aboriginal

aboriginal \ab-ə-'rij-nəl\ *adj.*

BIOLOGY. Relating to plants and animals that were first native to, or first to exist naturally in, a given region of the earth.

The kangaroo is an ABORIGINAL animal of Australia.

abrasion \ə-'brā-zhən\ *n.*

EARTH SCIENCE. A wearing away by friction, usually by rock particles carried in water, wind or ice.

The stream channel was deepened by ABRASION.

abrasive \ə-'brā-siv\ *n.*

A hard surface used to grind or polish other materials.

Sandpaper is used as an ABRASIVE to smooth rough wood surfaces.

abscess \ab-,ses\ *n.*

MEDICINE. A collection of pus in a swollen, inflamed part of the body, usually caused by bacterial infection.

In an ABSCESS, pus is formed by the disintegration of infected tissue.

abscissa \ab-'sis-ə\ *n.*

MATHEMATICS. The signed number that gives the direction and the distance to a point from the y-axis of a Cartesian coordinate system.

If the ordered pair (3, 2) represents a point in a coordinate system, then 3 is the ABSCISSA of the point.

absolute humidity \ab-sə-,lüt hyü-'mid-ət-ē\

EARTH SCIENCE. The mass of water vapor contained in a given quantity of air, usually expressed in grams per cubic meter.

ABSOLUTE HUMIDITY is ordinarily greater over water than over land.

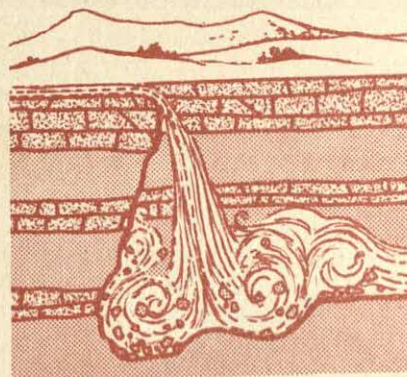
absolute temperature \ab-sə-,lüt 'tem-pər-,chü(ə)r\

CHEMISTRY and PHYSICS. A temperature scale that has as its lowest point absolute zero, used in the fundamental temperature scale in theoretical physics and chemistry; Kelvin temperature.

The ABSOLUTE TEMPERATURE scale is useful to the scientist because all temperatures are positive on this scale.

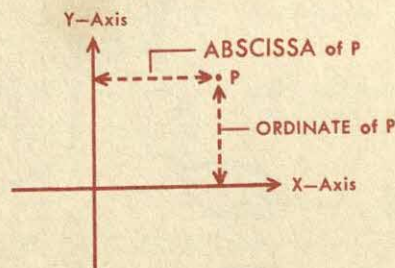
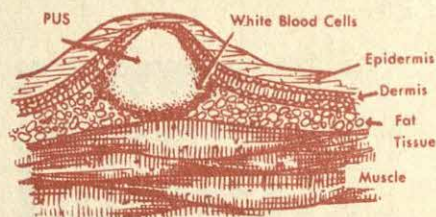
absolute value \ab-sə-,lüt 'val-(,)yü\

MATHEMATICS. The value of a signed number without regard for its sign; defined symbolically as: $|x| = x$ if x is greater than or equal to zero, $|x| = -x$ if x is less than zero, where the sym-



ABRASION

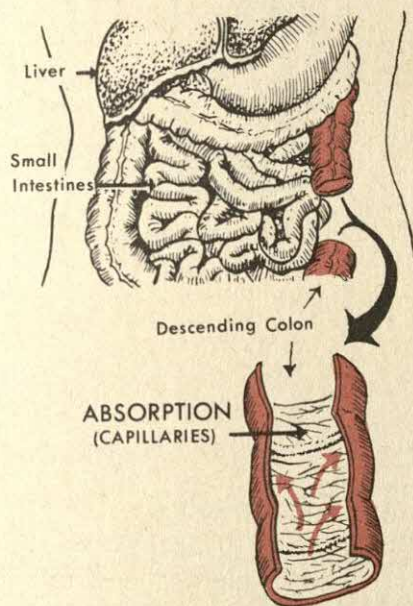
ABSCESS



acceleration

bol, $|x|$, denotes absolute value and " $|x|$ " is read "the absolute value of x ."

The ABSOLUTE VALUE of -2 is $-(-2)$, or 2 .



absolute zero \ 'ab-sə-,lüt 'zē-(,)rō \

CHEMISTRY and PHYSICS. The beginning or bottom point on the scale of absolute temperature (-273° C.); the temperature at which all thermal motion ceases.

Scientists have not been able to lower the temperature of an object to ABSOLUTE ZERO.

absorption \ əb-'sɔrp-shən \ n.

1. PHYSIOLOGY. The taking in of dissolved substances, such as foods, by live tissues; especially, the movement of digested foods through the lining of the alimentary canal into the blood.
2. CHEMISTRY. The taking in of a gas or liquid by another liquid or by a solid.
3. PHYSICS. The reduction or transformation of energy.

ABSORPTION is an important part of food assimilation.

absorption spectrum \ əb-'sɔrp-shən 'spek-trəm \

ASTRONOMY. A spectrum in which dark bands or lines appear because of the absorption of the light energy in those lines or regions by some matter lying between the source of the light and the instrument which produces the spectrum.

A star can be classified according to its ABSORPTION SPECTRUM.

abstract \ 'ab-,strakt \ adj.

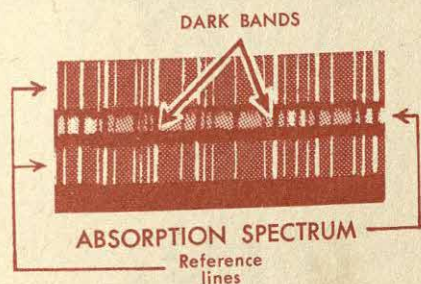
MATHEMATICS. Referring to a number or symbol that is not related to any particular thing.

Algebra is based on the use of ABSTRACT symbols.

abyssal \ ə-'bis-əl \ adj.

BIOLOGY and EARTH SCIENCE. Of, or found in, deep regions of the sea.

A number of ABYSSAL animals have light-producing organs.



AC

An abbreviation for alternating current. See *alternating current*.

acceleration \ ik-,sel-ə-'rā-shən \ n.

PHYSICS. The rate of change in the speed of a moving object, measured by the rapidity of the increase or decrease in velocity; also, a change in direction caused by an external force.

acceleration due to gravity

Newton's second law states that the ACCELERATION of a moving body is directly proportional to the force causing the change, inversely proportional to the mass of the moving body.

acceleration due to gravity \ik-,sel-ə-'rā-shən 'd(y)ü 'tü 'grav-ət-ē\

PHYSICS. The constant increase in speed of a falling body due to gravitational pull (about 32 feet per second in each second of fall at sea level).

Galileo demonstrated that ACCELERATION DUE TO GRAVITY is identical for all free-falling bodies, regardless of their weight.



Lead ball
and feather
fall at the
same speed
in vacuum

**ACCELERATION
DUE TO GRAVITY**

accelerator \ik-'sel-ə-rāt-ər\ *n.*

1. **CHEMISTRY.** A substance that quickens or slows down a chemical change or reaction. 2. **PHYSICS.** See *particle accelerator*.

A chemical compound often is used as an ACCELERATOR in the drying of paint.

acclimate \ə-'klī-mət\ *v.*

BIOLOGY. To become accustomed to a different environment.

Animals in the zoo usually ACCLIMATE to their new surroundings.

accommodation \ə-,kām-ə-'dā-shən\ *n.*

PHYSIOLOGY. The focal adjustment of the eye in viewing objects at different distances.

ACCOMMODATION results from a change in the shape of the lens in the eye.



ACCOMMODATION

accretion \ə-'krē-shən\ *n.*

1. **EARTH SCIENCE.** Increase in size of inorganic substances by the addition of particles from the outside. 2. **MEDICINE.** A growing together of parts usually separate, such as toes.

An icicle is an ACCRETION of frozen water droplets.

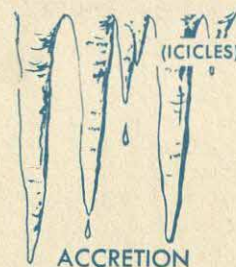
acetate \ 'as-ə-,tāt\ *n.*

CHEMISTRY. A salt or ester of acetic acid.

In dyeing fabrics, aluminum ACETATE can be used to make colors permanent.

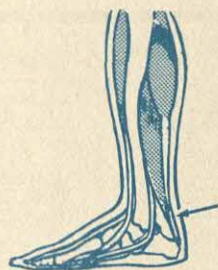
acetic acid \ə-'sēt-ik 'as-əd\

CHEMISTRY. CH_3COOH . A colorless, sour-tasting compound used in medicine and industry, obtained from alcohol by oxi-

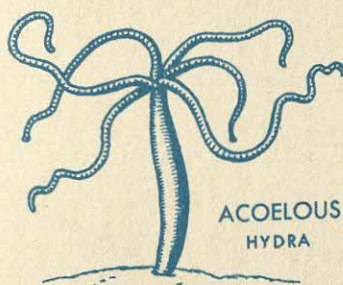
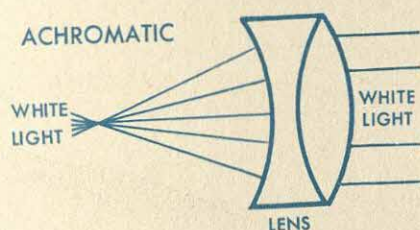


ACCRETION

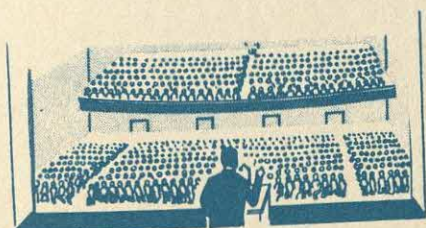
acoustics



ACHILLES TENDON



ACOELOUS
HYDRA



ACOUSTICS

Acetone is produced by distillation of wood by distillation or from acetylene by a catalytic process; also, the acid found in vinegar.

ACETIC ACID is stored in glass containers because it is corrosive to metals.

acetone \ 'as-ə-, tōn \ *n.*

CHEMISTRY. CH_3COCH_3 . A colorless, flammable liquid having a pleasant odor; a dimethyl ketone.

ACETONE is a solvent for certain varnishes.

acetylene \ ə- 'set- əl- ən \ *n.*

CHEMISTRY. $\text{HC}:\text{CH}$. A colorless gas that, when ignited, produces an intensely-hot white flame; an unsaturated hydrocarbon.

The high temperature produced by burning ACETYLENE in oxygen is used by welders to melt and fuse metals.

Achilles tendon \ ə- 'kil- (,) ēz 'ten- dən \

ANATOMY. The tendon that joins the calf muscle of the lower leg to the heel bone.

The ACHILLES TENDON is one of the largest tendons in the body.

achromatic \ ,ak-rə- 'mat-ik \ *adj.*

1. PHYSICS. Capable of changing the path of light without separating its colors, as in a telescopic lens. 2. Without color.

An ACHROMATIC lens is composed of a combination of convex and concave lenses, each having a different index of refraction.

acid \ 'as-əd \ *n.*

CHEMISTRY. A substance that yields hydrogen ions in solution, is sour to the taste and turns litmus paper red.

Lemon juice contains citric ACID.

acoelous \ (') ā- 'sē- ləs \ *adj.*

ZOOLOGY. Having no true stomach or digestive tract; also, without a body cavity or coelom.

The hydra is an ACOELOUS animal.

acoustics \ ə- 'kü- stiks \ *n.*

PHYSICS. The qualities that determine the clarity of sound in a room or enclosure; also, the science of sounds.

An auditorium is said to have good ACOUSTICS if words spoken on the stage can be heard distinctly throughout the room.

acre

acre \ˈā-kər\ *n.*

A unit of land; 43,560 square feet, or 160 square rods.

The area of a football field is somewhat less than an ACRE.

ACTH

PHYSIOLOGY. A hormone secreted by the pituitary gland that stimulates the secretion of cortisone by the cortex of the adrenal gland; an abbreviation for adrenocorticotrophic hormone.

Artificially-produced ACTH is sometimes used in the treatment of rheumatoid arthritis.

actinic rays \ak-ˈtin-ik ˈrāz\

PHYSICS. The waves of a spectrum of radiant energy, such as green, blue or ultraviolet in sunlight, that produce a photochemical effect.

ACTINIC RAYS affect the photographic film in a camera.

actinide series \ˈak-tə-,nīd ˈsi(ə)r-(,)ēz\

CHEMISTRY. The elements, with atomic numbers from 89 through 103, that are radioactive and do not usually occur in nature.

Uranium and thorium are the only two elements in the ACTINIDE SERIES that are not man-made.

activate \ˈak-tə-,vāt\ *v.*

CHEMISTRY and PHYSICS. To initiate or speed up reactions by various methods, such as heating.

Enzymes help ACTIVATE the digestive process.

acute angle \ə-ˈkyüt ˈaŋ-gəl\

MATHEMATICS. An angle of less than 90 degrees.

Every triangle has more than one ACUTE ANGLE.

Adam's apple \ˈad-əmz ˈap-əl\

ANATOMY. A projection at the front of the neck, caused by the union of cartilages and partly surrounded by the thyroid gland.

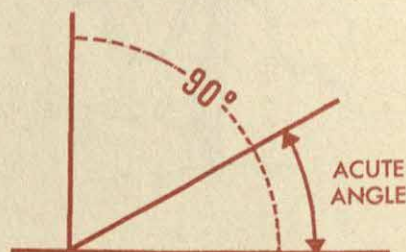
The ADAM'S APPLE moves in the act of swallowing.

adaptation \,ad-,ap-ˈtā-shən\ *n.*

1. BIOLOGY. Changes in the structure, function or form of plants and animals by which, over several generations, they become more able to survive in their environment. 2. PHYSIOLOGY. A lessening of body sensitivity due to continuous stimulation.

ACTINIDE SERIES

Actinium Ac 89	Berkelium Bk 97
Thorium Th 90	Californium Cf 98
Protactinium Pa 91	Einsteinium Es 99
Uranium U 92	Fermium Fm 100
Neptunium Np 93	Mendelevium Md 101
Plutonium Pu 94	Nobelium No 102
Americium Am 95	Lawrencium Lw 103
Curium Cm 96	



adenosine triphosphate

The polar bear's thick, white fur is an example of ADAPTATION to a cold, snowy climate.



adaptive radiation \ə-'dap-tiv ,rād-ē-'ā-shən\

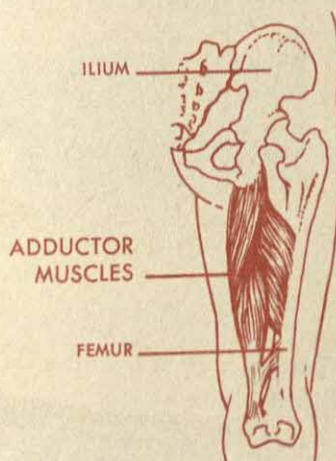
BIOLOGY. The change undergone by a group of organisms over several generations, by which the group is changed into subgroups with varying characteristics. The changes are the result of genetic interaction with differing environments.

Local differences in a species of fish may be the result of ADAPTIVE RADIATION.

adductor muscles \ə-'dək-tər 'məs-əlz\

ANATOMY. Muscles that pull limbs toward the midline of the body.

Some of the ADDUCTOR MUSCLES of the leg are located above the knee.



adenoids \'ad-ə-'n, -oidz\ n.

ANATOMY. A mass of lymphoid tissue similar to tonsils, but located in the upper part of the throat behind the nose.

Enlarged ADENOIDS may interfere with a child's breathing and speaking.

adenosine diphosphate \ə-'den-ə-,sēn ('dī-'fäs-,fāt\

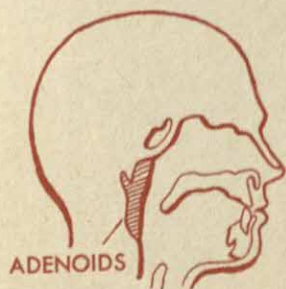
BIOLOGY. An organic molecule within every cell. It contains two phosphate groups and is always accompanied by adenosine triphosphate, another organic molecule containing three phosphate groups. The transfer of one phosphate group from adenosine triphosphate to it reverses the identity of the two molecules and releases the energy necessary to cell respiration. It is also produced from adenosine triphosphate when a muscle cell contracts; *abbr.* ADP; see *adenosine triphosphate*.

Mitochondria in a cell supply the energy necessary to convert ADENOSINE DIPHOSPHATE back to adenosine triphosphate.

adenosine triphosphate \ə-'den-ə-,sēn ('trī-'fäs-,fāt\

BIOLOGY. An organic molecule within every cell. It contains three phosphate groups and is always accompanied by adenosine diphosphate, another organic molecule containing two phosphate groups. The transfer of one phosphate group from it to adenosine diphosphate reverses the identity of the two molecules and releases the energy necessary to cell respiration and to muscle contraction; *abbr.* ATP; see *adenosine diphosphate*.

When a muscle cell contracts, its ADENOSINE TRIPHOSPHATE is converted to adenosine diphosphate.



adhesion

adhesion \ad-'hē-zhən\ *n.*

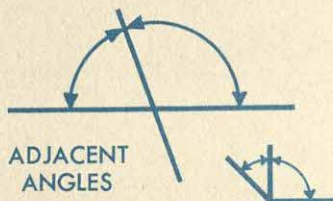
PHYSICS. The force causing unlike molecules to be attracted to one another.

When one writes on a chalkboard, chalk particles remain on the surface because of ADHESION between the molecules of the chalk and those of the chalkboard.

adiabatic lapse rate \,ad-ē-ə-'bat-ik 'laps 'rāt\

EARTH SCIENCE. A rate of change in temperature due to change in pressure, without addition of heat to, or loss from, the surrounding atmosphere.

The dry ADIABATIC LAPSE RATE is about $5\frac{1}{2}^{\circ}$ F. for each thousand feet of altitude.



adipose \'ad-ə-,pōs\ *adj.*

PHYSIOLOGY. Pertaining to animal fat; fatty.

Fat is stored in the body as ADIPOSE tissue.

adjacent angles \ə-'jās-ənt 'aŋ-gəlz\

MATHEMATICS. Two angles having a common vertex and also having a common side between them.

Two intersecting straight lines form four pairs of ADJACENT ANGLES.

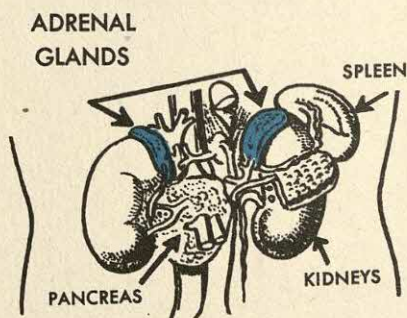
ADP

The abbreviation for adenosine diphosphate. See *adenosine diphosphate*.

adrenal glands \ə-'drēn-əl glandz\

PHYSIOLOGY. Endocrine or ductless glands located in the human body near the upper ends of the kidneys; composed of an inner section called the medulla and an outer portion called the cortex.

The two parts of the ADRENAL GLANDS secrete the hormones adrenaline and cortisone.



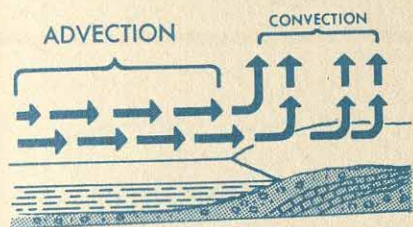
adrenaline \ə-'dren-əl-ən\ *n.*

PHYSIOLOGY. A hormone secreted by the medulla of the adrenal glands, that speeds heart action and increases blood pressure and blood sugar; adrenin.

Increased ADRENALINE in the blood decreases the time it takes the blood to clot.

adsorption \ad-'sōrp-shən\ *n.*

CHEMISTRY and PHYSICS. The adherence of atoms, molecules or



ions to the surface of a liquid or solid with which they are in contact.

Activated charcoal may be used to remove objectionable odors from water by ADSORPTION of substances in the water.

adulterate \ə-'dəl-tə-,rāt\ v.

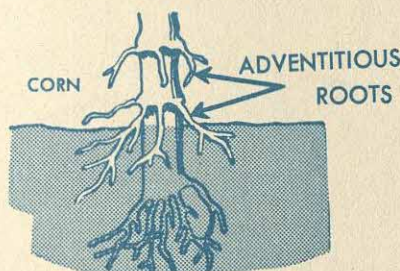
CHEMISTRY. To lessen the quality or purity of a substance by adding to it a foreign or cheaper substance.

It is forbidden by law to ADULTERATE food products that are offered for sale.

advection \ad-'vek-shən\ n.

EARTH SCIENCE. The horizontal movement of a mass of air.

ADVECTION can cause high-velocity winds.



adventitious roots \,ad-vən-'tish-əs 'rīts\

BOTANY. Plant roots that do not grow at the end of the stem.

The prop roots of corn, that serve as braces, are ADVENTITIOUS ROOTS.

aerate \a-(ə)r-,āt\ v.

1. PHYSICS. To introduce air or gas into a solid or liquid. 2. PHYSIOLOGY. Changing venous into arterial blood in the lungs by intake of oxygen and removal of carbon dioxide.

In the manufacture of carbonated beverages, carbon dioxide is used to AERATE the liquid.

aerial \ar-ē-əl\ adj.

BIOLOGY. Existing or growing in the air.

AERIAL roots grow from the leaves or stems of some plants.

aerobic \,a-(ə-)rō-bik\ adj.

BIOLOGY. Able to live only in the presence of free oxygen.

Bacteria can be classified as either AEROBIC or anaerobic.

aerobiology \,ar-ō-bī-'äl-ə-jē\ n.

BIOLOGY. The study of microscopic life forms found in air. These include pollen grains and plant spores, as well as bacteria.

Determining the pollen count of air samples during the summer months is a typical task in AEROBIOLOGY.

ORCHID PLANT



AERIAL (ROOTS)

aerodonetics

aerodonetics \,ar-ō-(,)dō-'net-iks\ *n.*

AERONAUTICS. The science that deals with gliding flight or gliding aircraft.

Glider pilots must be familiar with the principles of AERODONETICS.

aerodynamics \,ar-ō-(,)dī-'nam-iks\ *n.*

AERONAUTICS, ENGINEERING, and PHYSICS. The science of moving air and other gases in motion and the study of their physical properties.

An engineer in AERODYNAMICS may sometimes test model planes in a wind tunnel.

aeronautics \,ar-ə-'nót-iks\ *n.*

The science and technique of aircraft production and operation.

In the past half century, AERONAUTICS has become an important field of study.

aeropause \,ar-ō-'pōz\ *n.*

ASTRONAUTICS. A portion of the upper region of the atmosphere so thin that it will not support ordinary aircraft.

Missiles fired into outer space pass through the AEROPAUSE.

aerosol \,ar-ə,'säl\ *n.*

CHEMISTRY and PHYSICS. Extremely fine particles of liquid or solid matter suspended in gas or air; a fog or mist.

Insecticide or paint may be applied from a pressurized container as an AEROSOL.

aerospace \,ar-ō-'spās\ *n.*

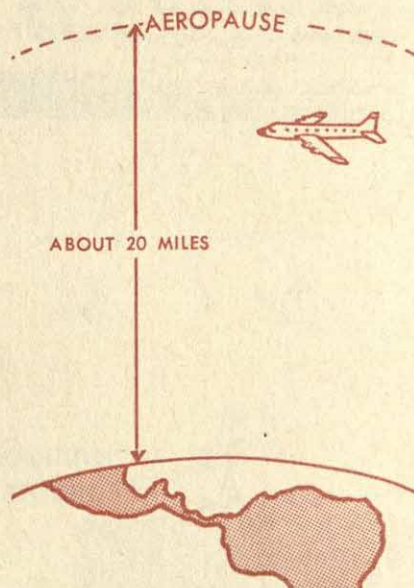
ASTRONAUTICS. All space beyond the earth's surface, including the atmosphere and outer space.

The development of powerful rockets has aided the scientist in his investigation of AEROSPACE.

aerostatic \,ar-ō-'stat-ik\ *adj.*

AERONAUTICS. Referring to balloons and dirigibles, or airships that make use of a rubberized bag or some other container filled with a lighter-than-air gas, such as helium or hydrogen.

Helium, being nonflammable, is the safest of the gases used in AEROSTATIC devices such as weather balloons.

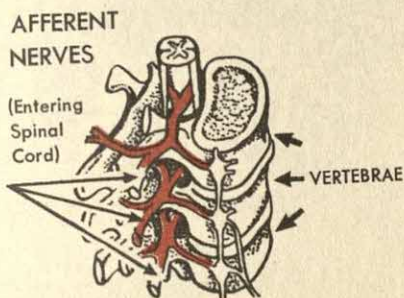


agglomerate

afferent nerves \af-ə-rənt 'nərvz\

ANATOMY. The nerves that conduct impulses to the spinal cord; opposed to efferent nerves.

Sensations of heat, cold, pressure and pain are carried by AFFERENT NERVES.



affinity \ə-'fin-ət-ē\ n.

CHEMISTRY. The force of attraction between unlike atoms by which chemical compounds are formed.

The principle of AFFINITY operates among celestial objects, as well as among atoms.

afterburner \af-tər-,bər-nər\ n.

AERONAUTICS. A device for burning extra fuel in the exhaust system of a jet engine. It uses any oxygen remaining in the hot gases ejected from the combustion chamber.

Extra thrust is provided by the AFTERBURNER attached to the tail pipe of a turbojet.

afterdamp \af-tər-,damp\ n.

CHEMISTRY. An unbreathable gas mixture, consisting mostly of carbon dioxide and nitrogen, that remains in mines after an explosion of firedamp.

Men going into a mine after an explosion must wear masks to protect themselves from AFTERDAMP.



agar \äg-,är\ n.

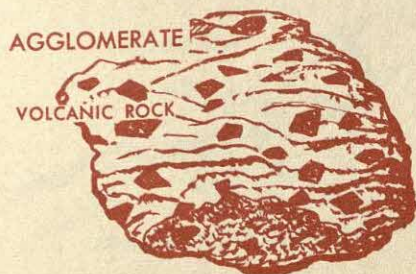
MEDICINE. A gelatinous substance obtained from certain seaweeds that, when mixed with other substances, is used as a medium for bacterial cultures; agar-agar.

A nutrient must be added to AGAR to enable bacterial growth to take place.

agent \ä-jənt\ n.

CHEMISTRY. An element or substance that produces a change or reaction.

A catalyst is one kind of chemical AGENT.



agglomerate \ə-'gläm-ə-rət\ n.

EARTH SCIENCE. A rock made up of angular volcanic fragments of several sizes and shapes.

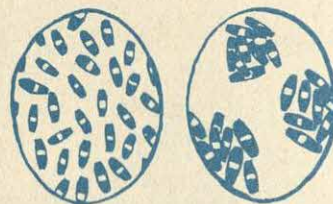
An AGGLOMERATE is found in areas where volcanic eruptions have occurred.

agglutination

agglutination \ə,glüt-^ən-'ā-shən\ *n.*

1. **PHYSIOLOGY.** The clumping together of bacteria or blood cells upon the introduction of certain antibodies. 2. **MEDICINE.** The growing together, or adhesion, of the surfaces of a wound.

AGGLUTINATION would occur if type B blood were given to a patient with type A blood.



AGGLUTINATION

agonic line \(')ā-'gän-ik 'līn\

EARTH SCIENCE. An imaginary line on the earth's surface that passes through points where a compass needle will indicate true north.

The AGONIC LINE is a line along which there is zero magnetic declination.

aileron \ā-lə-'rānz\ *n.*

AERONAUTICS. The movable control surfaces on airplane wings used to bank the plane.

The AILERONS of an airplane are used to maintain horizontal stability.

air \a(ə)r\ *n.*

CHEMISTRY and EARTH SCIENCE. An odorless, colorless mixture of oxygen, nitrogen and water vapor, with small amounts of other gases; the earth's atmosphere.

Wind is the movement of AIR.



air bladder \a(ə)r 'blad-ər\

ZOOLOGY. An inflatable sac or pocket in the body of a fish by which it can change its buoyancy; also, in air-breathing fish, a lung.

The AIR BLADDER in a lungfish is thought to be a holdover from an earlier evolutionary stage.

air brake \a(ə)r 'brāk\

1. **AERONAUTICS.** On an aircraft, a broad surface that can be projected into the air stream to increase air resistance and thereby lower the speed of the craft. 2. **ENGINEERING.** A system of brakes for trains and large automotive vehicles in which the force to release brakes (trains) or apply brakes (trucks or buses) is supplied by compressed air.

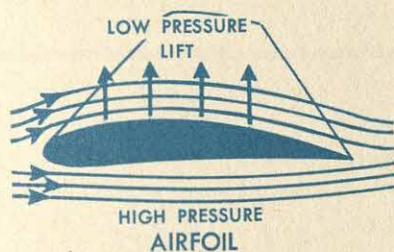
When wing flaps on an aircraft are lowered, they act as an AIR BRAKE.



air-condition \,a(ə)r-kən-'dish-ən\ *v.*

ENGINEERING. To treat the air by one or more of the following:

air sacs



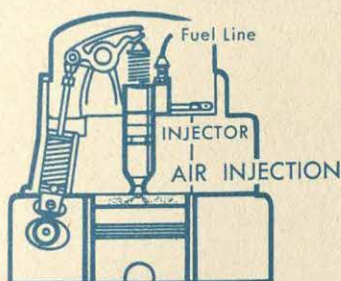
by purifying it, by controlling its temperature and by controlling its humidity.

It is easier to AIR-CONDITION a well-insulated house than one that is poorly insulated.

airfoil \ 'a(ə)r-fôil\ n.

AERONAUTICS. A surface, such as a wing, designed to lift and control an aircraft.

Most of the lift is produced on the upper surface of the AIRFOIL.



air injection \ 'a(ə)r in-'jek-shən\

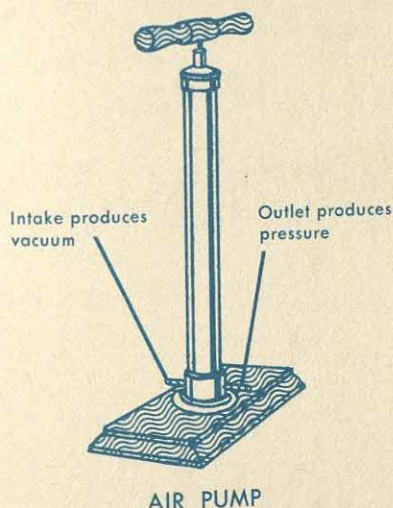
ENGINEERING. The injection of atomized fuel oil into the combustion chamber of an engine by using compressed air.

The invention of AIR INJECTION made faster and more efficient combustion possible.

air mass \ 'a(ə)r 'mas\

EARTH SCIENCE. A large body of air that has approximately the same temperature and humidity at any given level. The four main types are arctic, polar, tropic and equatorial.

The weather bureau can predict the weather by studying the position and movement of an AIR MASS.



air pocket \ 'a(ə)r 'päk-ət\

1. PHYSICS. An air-filled space in a liquid or solid. 2. AERONAUTICS. Vertical air currents that cause an airplane to drop suddenly; a layman's term for updrafts and downdrafts.

An AIR POCKET in the gas line of a car may cause the engine to stall.

air pressure \ 'a(ə)r 'presh-ər\

PHYSICS. The force per unit of area exerted by the atmosphere or by a confined gas.

A barometer is used to measure atmospheric AIR PRESSURE.

air pump \ 'a(ə)r 'pəmp\

ENGINEERING. A mechanism for causing air to flow, thus increasing or decreasing air pressure within an enclosed space.

An AIR PUMP can be used to create an almost total vacuum.



air sacs \ 'a(ə)r 'saks\

ZOOLOGY. Air pockets in the bodies of birds that are connected with the respiratory system; dilated tracheae in some insects, such as the honeybee; the alveoli in the lungs.

AIR SACS in birds help carry away excess body heat.

alabaster

alabaster \al-ə-,bas-tər\ *n.*

EARTH SCIENCE. A white or delicately-shaded variety of gypsum used for ornamental objects, such as figurines.

The base platforms of some lamps are made of ALABASTER.

albedo \al-'bēd-(,)ō\ *n.*

ASTRONOMY. The ratio between the light reflected by an object and the total light shining on it.

Since the moon reflects approximately seven percent of the sunlight that shines on it, its ALBEDO is seven percent.

albino \al-'bī-(,)nō\ *n.*

BIOLOGY. An animal or plant lacking in genes for pigmentation that give it natural color.

A rabbit with white fur and pink eyes is an ALBINO.

albumin \al-'byü-mən\ *n.*

BIOLOGY. A protein substance composed of nitrogen, carbon, hydrogen, oxygen and sulfur, found in plant and animal tissues and fluids.

ALBUMIN is an important part of blood serum.

alcohol \al-kə-,hól\ *n.*

CHEMISTRY. An organic compound containing one or more hydroxyl (OH) groups and one or more hydrocarbon groups.

Certain kinds of ALCOHOL are used to prevent the freezing of the fluid in automobile radiators.

aldehyde \al-də-,hīd\ *n.*

CHEMISTRY. One of a group of organic compounds with the general formula R—CHO, that yields acids under oxidation and alcohols when reduced.

One ALDEHYDE, named formaldehyde, is used to preserve biological specimens in laboratories.

algebra \al-jə-brə\ *n.*

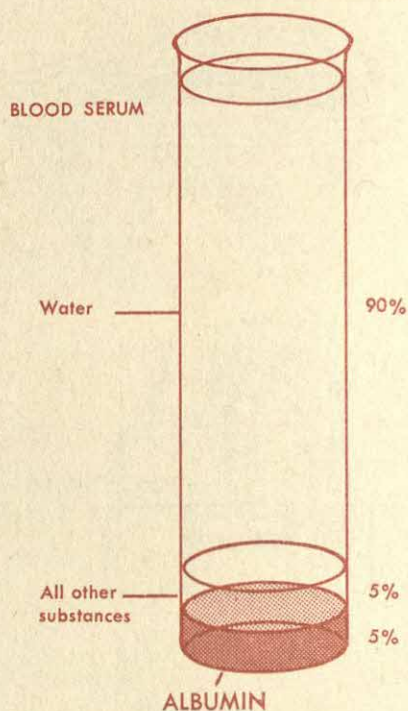
MATHEMATICS. A mathematical system in which letters and symbols are substituted for actual numbers so that theoretical relationships between quantities may be determined.

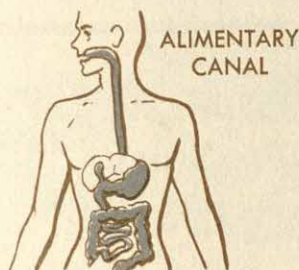
ALGEBRA is a method of dealing with an unknown quantity mathematically.

alidade \al-ə-,dād\ *n.*

EARTH SCIENCE and ENGINEERING. A sighting instrument for determining heights and distances, as in surveying.

Highway engineers are among those who use an ALIDADE.





alimentary canal \,al-ə-'ment-ə-rē kə-'nal\

ANATOMY and ZOOLOGY. The tubular tract in an animal, including, in man, the esophagus, stomach and intestines, through which food passes and is digested; the digestive tract.

The ALIMENTARY CANAL in an adult man is 25 to 30 feet long.

alkali \ 'al-kə-,lī\ n.

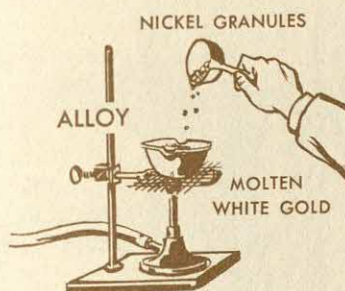
CHEMISTRY. A compound, such as sodium carbonate, potassium hydroxide or sodium hydroxide, with marked basic chemical properties. An alkali combines with acids to form salts.

An ALKALI can be used to neutralize an acid.

alkaloid \ 'al-kə-,lōid\ n.

CHEMISTRY and MEDICINE. A basic nitrogenous compound that occurs principally in living plants.

An ALKALOID is a common ingredient of many drugs.



allele \ə-'lē(ə)l\ n.

BIOLOGY. Either of a pair of contrasting hereditary traits determined by genes, as light eyes or dark eyes; also, allelomorph.

When a pea plant has the dominant ALLELE for tallness and the contrasting recessive genes that produce dwarfness, the plant appears tall and is hybrid for this trait.

allergy \ 'al-ər-jē\ n.

MEDICINE. An abnormal sensitivity of the body to certain substances, such as foods, pollens, medicines and dust, or to conditions, such as heat and cold.

Sneezing is sometimes a symptom of an ALLERGY.

alloy \ 'al-,ōi\ n.

CHEMISTRY. A mixture of two or more metals soluble in each other when molten, then cooled to the solid state.

Many rings are made of white gold, an ALLOY composed of gold and other metals.



alluvium \ə-'lü-vē-əm\ n.

EARTH SCIENCE. Soil, gravel, sand or stones deposited by running water.

ALLUVIUM is found in riverbeds, lakes and flood plains.

alpha \ 'al-fə\ adj.

1. ASTRONOMY. Referring to the brightest star in a constellation.
2. CHEMISTRY. Referring to the possible position of substituted

alpha ray

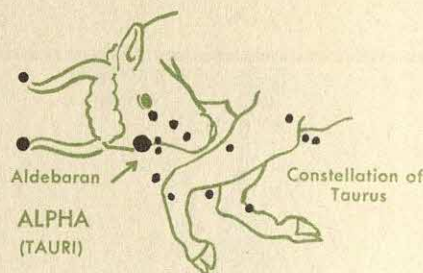
atoms in a compound. 3. First letter in the Greek alphabet; also, referring to something classified as first.

Aldebaran is known also as ALPHA Tauri, because it is the brightest star in Taurus.

alpha ray \ 'al-fə 'rā \

PHYSICS. A stream of positively-charged particles called alpha particles, emitted in the decay of radioactive substances; one of the three rays (alpha, beta, gamma) given off by radioactive substances.

ALPHA RAY particles are composed of two protons and two neutrons.



alternating current \ 'ól-tər-nāt-i-j 'kər-ənt \

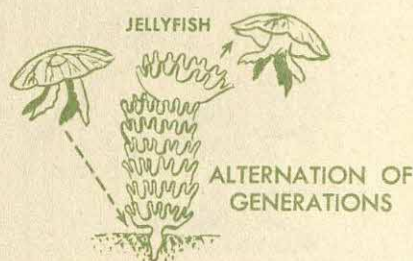
PHYSICS. An electric current whose direction is reversed at regular intervals; *abbr.* AC.

The most common form of electric power in the home is provided by ALTERNATING CURRENT.

alternation of generations \,ól-tər-'nā-shən əv ,jen-ə-'rā-shənz \

BIOLOGY. A method of reproduction among certain life forms in which organisms of one type produce organisms of another type, with the original or parent type not reappearing again for one or more generations; usually an alternation of a sexual with an asexual form.

ALTERNATION OF GENERATIONS is a characteristic of jellyfish.



altimeter \al-'tim-ət-ər \ n.

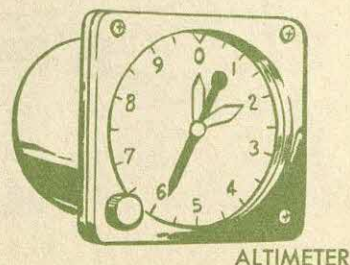
AERONAUTICS. An aneroid barometer adapted for determining altitude.

An ALTIMETER is a standard aircraft instrument.

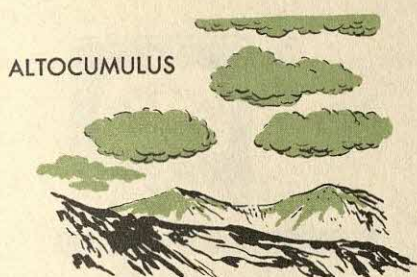
altitude \ 'al-tə,t(y)üd \ n.

1. EARTH SCIENCE. Elevation above a given level, usually height above sea level. 2. ASTRONOMY. The elevation of a celestial object above the horizon, measured in degrees. 3. MATHEMATICS. In geometric figures, the perpendicular (*a*) to a side from any point on the opposite side (parallelogram); (*b*) from the vertex to the plane of the base (cone or pyramid); (*c*) from any point on the base to the plane of the other base (cylinder or prism); (*d*) from any vertex to the opposite side (triangle).

During the summer months, snow on a mountain is usually found at a high ALTITUDE.



amber



altocumulus \,al-(,)tō-'kyü-myə-ləs\ *adj.*

EARTH SCIENCE. Referring to a white cloud formation consisting of patches or layers of globular masses.

ALTOCUMULUS clouds often indicate an approaching storm.

altostratus \,al-(,)tō-'strāt-əs\ *adj.*

EARTH SCIENCE. Pertaining to a gray, formless cloud mass that occurs at a moderately-high altitude.

ALTOSTRATUS clouds usually lie in layers and are spread over large areas.

alum \ 'al-əm\ *n.*

CHEMISTRY. A double salt, such as $KAl(SO_4)_2 \cdot 12H_2O$, composed of sulfates of a trivalent metal, such as aluminum, iron or chromium, and a univalent metal, such as sodium or potassium, or the ammonium ion.

ALUM is used in a styptic pencil to help stop bleeding.

aluminum \ə-'lü-mə-nəm\ *n.*

CHEMISTRY. A light, pliable, silvery-white metallic element refined from the mineral bauxite and used extensively in products requiring light weight. Symbol, Al; atomic number, 13; atomic weight, 26.98.

The walls of many new office buildings are made of ALUMINUM.

alveola \al-'vē-ə-lə\ *n.*

BOTANY. A small pit or hollow, such as those that appear on the receptacle of a composite flower when the petals have fallen; usually numerous, they form a pattern similar to a honeycomb; also, a pore of some fungi.

In fungi of the genus Polyporus, a spore comes from an ALVEOLA under the shelflike fruiting bodies, not from narrow gills.

AM

Abbreviation for amplitude modulation. See *amplitude modulation*.

amalgam \ə-'mal-gəm\ *n.*

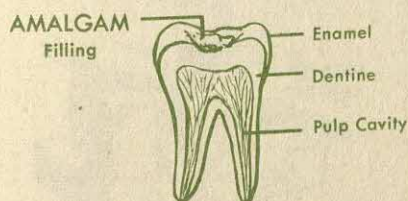
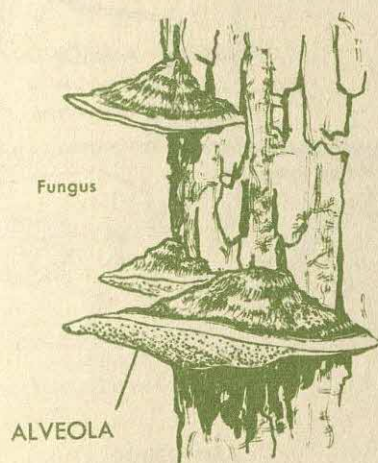
CHEMISTRY. An alloy of one or more metals with mercury.

A dentist uses an AMALGAM for filling cavities in teeth.

amber \ 'am-bər\ *n.*

EARTH SCIENCE. A hard, yellowish fossil resin or gum.

Some necklaces and bracelets are made of AMBER.



amino acids

amino acids \ə-'mē-(,)nō 'as-ədʒ\

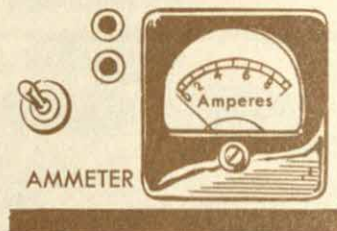
PHYSIOLOGY. The basic components of protein, obtained by the breakdown of protein during digestion, then re-formed as proteins in body cells.

Meat, eggs and milk provide the essential AMINO ACIDS needed in our daily diet.

ammeter \ 'am-,ēt-ər\ n.

ENGINEERING and PHYSICS. An instrument used to measure electric current.

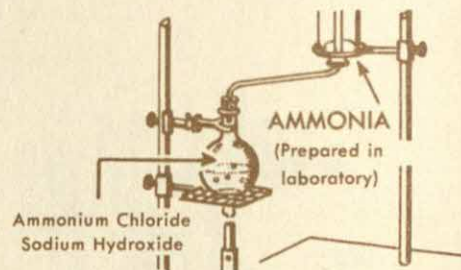
Television repairmen frequently use an AMMETER.



ammonia \ə-'mō-nyə\ n.

CHEMISTRY. NH_3 . A gaseous compound, colorless and strong-smelling.

AMMONIA is formed by the decomposition of protein materials containing nitrogen.



amorphous \ə-'môr-fəs\ adj.

1. CHEMISTRY. Uncrystallized. 2. EARTH SCIENCE. Without form; referring to materials, usually minerals, that have no crystalline structure.

Gum is an AMORPHOUS substance.

ampere \ 'am-,pi(ə)r\ n.

PHYSICS. A unit of measure for an electric current; the amount of current in a circuit in which the electromotive force is one volt and the resistance is one ohm.

The AMPERE is generally used for measuring electric current.

amphibian \am-'fib-ē-ən\ n.

ZOOLOGY. One of a class of vertebrates characterized by a three-chambered heart, cold-bloodedness and skin lacking hair, scales or feathers. Many species hatch and develop in the water, getting oxygen by use of gills, and later develop lungs and spend part of their adult lives on land.

The frog is an AMPHIBIAN.



amphoteric \,am(p)-fə-'ter-ik\ adj.

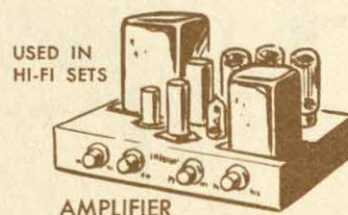
CHEMISTRY. Reacting either as an acid or as a base.

Antimony hydroxide is an AMPHOTERIC compound.

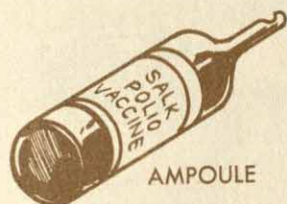
amplifier \ 'am-plə-,fī(ə)r\ n.

ENGINEERING and PHYSICS. An electronic device that increases the amplitudes of electric impulses or waves.

An AMPLIFIER is used in a radio to increase the volume of sound.



analog computer



AMPOULE

amplitude \ˈam-plə-,t(y)üd\ n.

PHYSICS. The value, size, volume or strength of a quantity. As applied to such waves as those of sound and electricity, amplitude refers to the maximum departure of the wave from its average value.

The volume of sound depends on the AMPLITUDE of the sound waves.

amplitude modulation \ˈam-plə-,t(y)üd ,mäj-ə-ˈlā-shən\

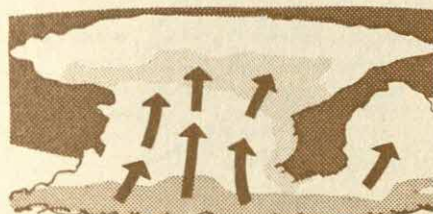
ENGINEERING. Radio broadcasting in which the carrier wave is modulated by varying its amplitude; *abbr.* AM.

The use of AMPLITUDE MODULATION is the most common form of radio broadcasting.

ampoule \ˈam-(,i)pyü(ə)l\ n.

MEDICINE. A small container that can be sterilized and sealed airtight to protect the purity of drugs and other substances.

Salk vaccine may be stored in an AMPOULE.



ANABATIC
(AIR CURRENTS)

anabatic \,an-ə-ˈbat-ik\ adj.

EARTH SCIENCE. Referring to winds that result from the upward movement, or convection, of warm air.

An ANABATIC wind always precedes the development of a thunderhead.

anabolism \ə-ˈnab-ə-,liz-əm\ n.

BIOLOGY and PHYSIOLOGY. The process in plants and animals that changes foods into living tissue; opposite of catabolism.

ANABOLISM is an energy-using process.

anadromous \ə-ˈnad-rə-məs\ adj.

ZOOLOGY. Referring to an ocean-dwelling fish that enters freshwater rivers to spawn.

The shad is an ANADROMOUS fish that is often found in fresh water in great numbers.

anaerobic \,an-ə-ˈrō-bik\ adj.

BIOLOGY. Able to live in the absence of free oxygen; pertaining to an oxygen-independent form of respiration.

A species of ANAEROBIC bacteria causes tetanus.



ANAEROBIC
(TETANUS BACTERIA)

analog computer \ˈan-ə-l,ög kəm-ˈpyüt-ər\

MATHEMATICS. An instrument that solves mathematical problems by measuring such physical quantities as pressure, voltage or hydraulic force.

An ANALOG COMPUTER is often used in manufacturing.

analysis

analysis \ə-'nal-ə-səs\ *n.*

1. **CHEMISTRY.** The determination of the component parts or elements of a substance or compound, qualitatively, quantitatively or both. 2. **MATHEMATICS.** The process of planning a proof by working backward from the conclusion to the given condition; also, that part of mathematics that is concerned largely with the study of the limit processes and that uses the methods of algebra and of calculus in examining mathematical systems and in solving problems taken from various fields of science and mathematics.

In a modern laboratory, the chemist has several ways to make a chemical ANALYSIS.

analytic geometry \,an-ə-'it-ik jē-'äm-ə-trē\

MATHEMATICS. Geometry treated with algebraic methods.

ANALYTIC GEOMETRY considers lines and circles as paths of moving points that are easily described by equations.

anaphase \'an-ə-,fāz\ *n.*

BIOLOGY. A stage in late mitotic cell division noted by the movement of chromosomes toward opposite ends of the spindle.

During ANAPHASE, each central body becomes associated with a complete and identical set of chromosomes.

anatomy \ə-'nat-ə-mē\ *n.*

The science of animal and plant structure; also, the particular physical structure of an organism.

Ancient papyrus scrolls show that the Egyptians of 1600 B.C. were interested in ANATOMY.

androgen \'an-drə-jən\ *n.*

PHYSIOLOGY. Any male hormone that controls the development of secondary sex characteristics.

One kind of ANDROGEN, testosterone, has been produced in the laboratory.

anemia \ə-'nē-mē-ə\ *n.*

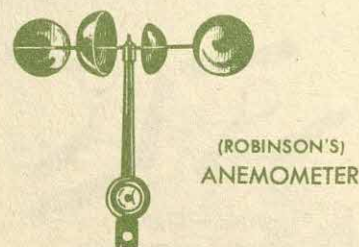
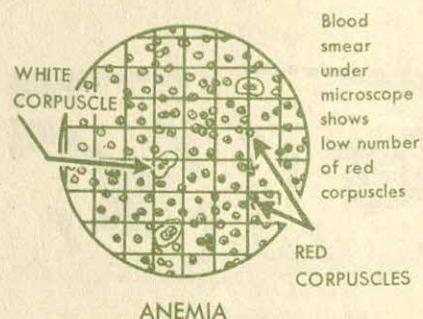
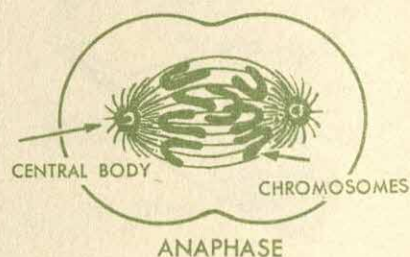
MEDICINE. A condition in which the blood lacks a sufficient quantity of red corpuscles, of hemoglobin in the red corpuscles or of both.

A test for ANEMIA is part of a complete physical examination.

anemometer \,an-ə-'mäm-ət-ər\ *n.*

EARTH SCIENCE. An instrument used for measuring wind velocity.

The ANEMOMETER does not measure gusts of wind accurately.





ANGIOSPERMS

aneroid barometer \an-ə-rōid bə-'räm-ət-ər\

EARTH SCIENCE. An instrument used to measure air pressure; a device consisting of a small, sealed metal container, partially exhausted of air, with a flexible surface attached to a pointer that indicates air pressure on an adjacent scale.

Unlike a mercury barometer, the ANEROID BAROMETER contains no liquid.

anesthetic \an-əs-'thet-ik\ *n.*

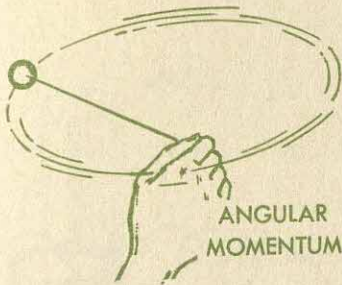
MEDICINE. A substance, such as ether, that causes a loss of sensation of pain or touch, or produces unconsciousness.

The discovery of ANESTHETIC was a great boon to surgery.

angiosperms \an-jē-ə-spərmz\ *n.*

BOTANY. Plants that have seeds enclosed in seed pods, such as nuts, berries and fruits; the flowering plants.

The ANGIOSPERMS are a major plant group.

**angstrom unit** \an-strəm 'yü-nət\

PHYSICS. One hundred-millionth of a centimeter, or 10^{-8} cm.; used to express atomic measurements and the length of very short waves.

An atom of hydrogen is about 0.6 of an ANGSTROM UNIT in diameter.

angular acceleration \an-gyə-lər ik-sel-ə-'rā-shən\

AERONAUTICS and PHYSICS. The rate at which a moving body is changing direction.

ANGULAR ACCELERATION may be expressed in radians per second or per minute, a radian being an angle equal to 57.29 degrees.

angular momentum \an-gyə-lər mō-'ment-əm\

PHYSICS. The force of rotation of a body turning about an axis; the product of the movement of inertia and the angular velocity of a rotating body.

The ANGULAR MOMENTUM of a ball being whirled at the end of a string depends upon the mass of the ball and its angular velocity.



ANGULAR VELOCITY

angular velocity \an-gyə-lər və-'lās-ət-ē\

PHYSICS. The rate of angular motion; the rate of motion of a rotating body.

Friction reduces the ANGULAR VELOCITY of a bicycle wheel.

anhydrous

anhydrous \(')an-'hī-drəs\ *adj.*

CHEMISTRY. Without water.

ANHYDROUS *copper sulfate*, CuSO_4 , is white but the hydrated form, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, is blue.

aniline \(')an-'l-ən\ *n.*

CHEMISTRY. An oily, poisonous liquid, slightly basic, colorless when refined, obtained by the reduction of nitrobenzene.

ANILINE is used in producing dyes, medicines and photographic materials.

animal \(')an-ə-məl\ *n.*

ZOOLOGY. Any of the group of living things that are characterized by voluntary movement from place to place, by sensitivity to external and internal stimulation and by their ingestion of animal and plant substances to maintain their body tissues. Animals are generally distinguished as a group of living things that do not have plant characteristics, such as chlorophyll content and the photosynthesis process.

A sponge, an insect, a bird, a fish and a snake are each classified as an ANIMAL.

animal classification \(')an-ə-məl ,klas-ə-fə-'kā-shən\

ZOOLOGY. The division of the animal kingdom into related groups and subgroups. The divisions are phylum, class, order, family, genus and species; see *binomial nomenclature*.

ANIMAL CLASSIFICATION was begun by the great Greek investigator, Aristotle.

anion \(')an-'ī-ən\ *n.*

CHEMISTRY and PHYSICS. A negatively-charged ion; also, a negatively-charged radical.

In an electrolytic solution, an ANION will move toward the positive electrode.

anneal \ə-'nē(ə)l\ *v.*

CHEMISTRY. To heat and cool slowly, under controlled conditions, such materials as glass, earthenware or metals, to reduce strains and to make them less brittle.

Several days are required to ANNEAL plate glass properly.

annual \(')an-yə(-wə)l\ *n.*

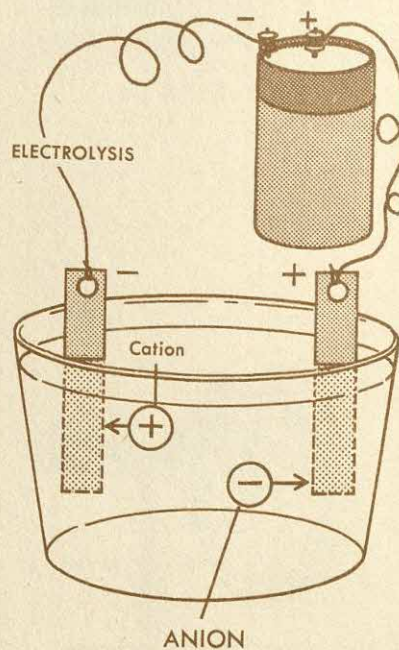
BOTANY. A plant that completes its life cycle in one year or one season.

The sunflower plant is an ANNUAL.

ANIMAL CLASSIFICATION (OF SONG SPARROW)



Phylum: Chordata
Class: Aves
Order: Passeriformes
Family: Fringillidae
Genus: Melospiza
Species: melodia



antheridium

annual ring \ˈan-yə(-wəl) ˈriŋ\

BOTANY. The circular markings seen in the cross section of a tree or shrubby stem, formed by differences in wood growth during different parts of the year, by which the age of the plant may be estimated.

The outer ANNUAL RING of a giant sequoia tree may be many feet in diameter.



anode \ˈan-ōd\ n.

CHEMISTRY and PHYSICS. The electrode at which electrons are given up by an element or an ion.

In a dry cell, the ANODE is usually made of zinc.

anoxia \a-ˈnäk-sē-ə\ n.

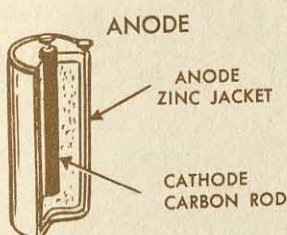
PHYSIOLOGY. An oxygen deficiency in blood or tissues.

A pilot flying without an oxygen mask at high altitude may black out because of ANOXIA.

antarctic \(')ant-ˈärk-tik\ adj.

EARTH SCIENCE. Of or pertaining to the South Pole or south polar region.

The area of the ANTARCTIC continent is larger than that of the United States.



antenna \an-ˈten-ə\ n.

1. **ZOOLOGY.** A movable, hairlike organ of touch, usually in pairs on an insect's head; frequently called "feelers." 2. **ENGINEERING.** Conductors for transmitting and receiving radio and television waves; an aerial.

An insect can move one ANTENNA independently of the other.

anterior \an-ˈtir-ē-ər\ adj.

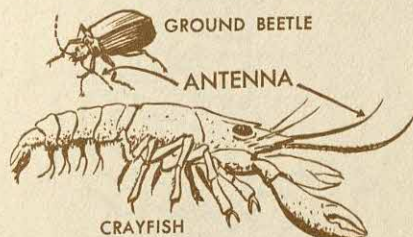
ANATOMY and BIOLOGY. Toward the front; also, situated near the head.

Antennae are located on the ANTERIOR portion of an insect.

anther \ˈan(t)-thər\ n.

BOTANY. In a flower, the small tip of the stamen that produces and contains pollen.

The ANTHER and the filament form the stamen of a flower.



antheridium \ˈan(t)-thə-ˈrid-ē-əm\ n.

BOTANY. In simple, nonflowering plants, such as mosses and

anthracite

ferns, a structure that is similar to the anther of flowering plants, in which male reproductive cells are formed and stored.

The cells formed in an ANTHERIDIUM may be compared to the pollen formed in an anther.

anthracite \ˈan(t)-thrə-,sīt\ n.

EARTH SCIENCE. A hard, black, lustrous coal that burns efficiently and is therefore valued for its heating quality.

Most of the ANTHRACITE mined in the United States comes from eastern Pennsylvania.

anthropoid \ˈan(t)-thrə-,pōid\ n.

ZOOLOGY. An ape that resembles man, such as the gibbon, chimpanzee or gorilla.

An ANTHROPOID, like man, has an opposable thumb.

anthropologist \,an(t)-thrə-ˈpäl-ə-jəst\ n.

A scientist who studies the historical development of man: his physical structure, social systems, racial connections and distribution over the earth.

An ANTHROPOLOGIST should have a good knowledge of human anatomy.

antibiotic \,ant-i-(-)bī-ˈät-ik\ n.

MEDICINE. A substance produced by living microorganisms, such as bacteria or fungi, that inhibits or kills specific bacteria.

An ANTIBIOTIC is used by doctors to help fight infection.

antibody \ˈant-i-,bäd-ē\ n.

MEDICINE and PHYSIOLOGY. A substance developed by immunization, or existing naturally in the blood and other body fluids, that counteracts bacterial infections.

A vaccine stimulates the formation of an ANTIBODY.

anticline \ˈant-i-,klīn\ n.

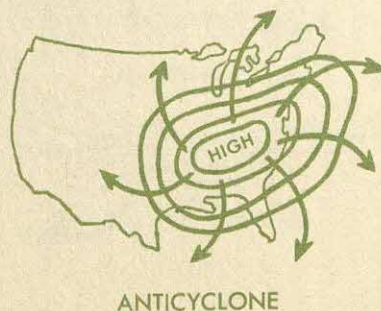
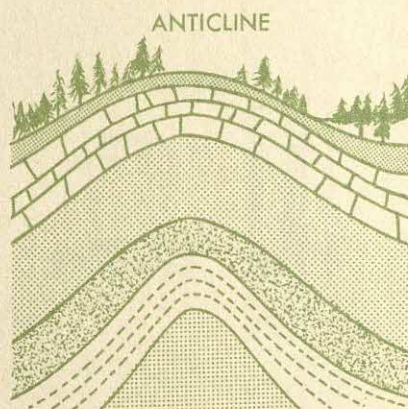
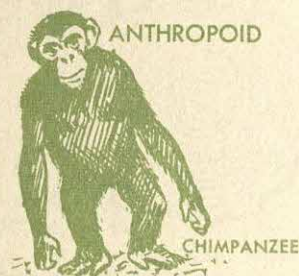
EARTH SCIENCE. An arch of stratified rock in which strata slope downward in opposite directions from a crest.

An ANTICLINE is the result of horizontal compression of a part of the earth's crust.

anticyclone \,ant-i-ˈsī-,klōn\ n.

EARTH SCIENCE. An extensive movement of air spiraling around and outward from a center of high pressure.

The winds of an ANTICYCLONE spiral outward in a clockwise direction in the Northern Hemisphere.



antimony

antidote \ˈant-i,dōt\ n.

MEDICINE. A substance used to counteract the effects of poison.

Olive oil is sometimes used as an ANTIDOTE for ammonia poisoning.

antigen \ˈant-i-jən\ n.

MEDICINE. A substance injected into animal tissue to stimulate the production of antibodies.

The principle of vaccination depends upon the introduction of an ANTIGEN.

antigravity suit \,ant-i-ˈgrav-ət-ē ˈsüt\

ASTRONAUTICS. A special garment developed by space scientists to allow astronauts to stand upright or move about while exposed to the forces of acceleration or deceleration. Without such equipment, too much blood is forced away from the brain, resulting in unconsciousness.

Inflation of the lower part of the ANTIGRAVITY SUIT makes it fit so tightly that the flow of blood away from the head is impeded.

antihistamine \,ant-i-ˈhis-tə-mēn\ n.

MEDICINE. A drug that checks the effect of histamine in the body; used in the treatment of allergies and colds.

An ANTIHISTAMINE can help alleviate the symptoms of hay fever.

antilogarithm \,ant-i-ˈlög-ə-rith-əm\ n.

MATHEMATICS. The number whose logarithm is the given number.

If 5 is the logarithm for 32, then 32 is also called the ANTILOGARITHM of 5.

antimatter \ˈant-i-mat-ər\ n.

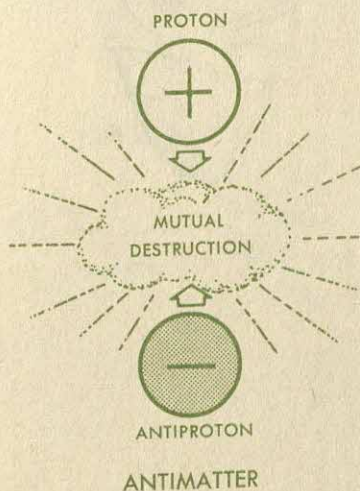
CHEMISTRY and PHYSICS. Matter containing positrons, antiprotons and antineutrons, subatomic particles with opposite properties to electrons, protons and neutrons. It does not exist within atoms.

When the subatomic particles of ANTIMATTER collide with their atomic opposites, they create energy as they destroy each other.

antimony \ˈant-ə,mō-nē\ n.

CHEMISTRY. An element of metallic appearance that sometimes occurs in a free state, but more often in combination with minerals and metal ores. Symbol, Sb; atomic number, 51; atomic weight, 121.75.

ANTIMONY is used in making low-melting alloys.



antiparticle

antiparticle \ˈant-i,-pärt-i-kəl\ *n.*

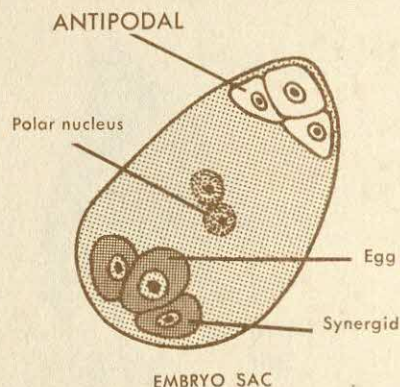
CHEMISTRY and PHYSICS. A positron, antiproton or antineutron, subatomic particles with opposite properties to the electron, the proton and the neutron.

Physicists produce an ANTIPARTICLE by means of a particle accelerator, as a by-product of nuclear bombardment.

antipodal \an-ˈtip-əd-əl\ *n.*

BOTANY. Any of three cell nuclei in the embryo sac of a flowering plant. It is located at the end of the embryo sac farthest from the micropyle and serves no known function.

After the egg of a seed plant is fertilized, each ANTIPODAL usually deteriorates and disappears.



antiseptic \ˌant-ə-ˈsep-tik\ *n.*

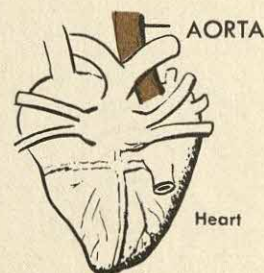
MEDICINE. A substance that destroys or arrests the growth of bacteria.

Soap can be used as an ANTISEPTIC.

antitoxin \ˌant-i-ˈtāk-sən\ *n.*

MEDICINE. An antibody produced in the body of an animal upon the introduction of a toxin and, when extracted from the animal, used to immunize humans or animals against the same toxin.

An ANTITOXIN is used to prevent disease.



aorta \ā-ˈört-ə\ *n.*

ANATOMY. The main artery of the circulatory system that carries blood from the heart to various branch arteries of the body.

The AORTA is the largest artery in the body.

aperture \ˈap-ə(r)-,chü(ə)r\ *n.*

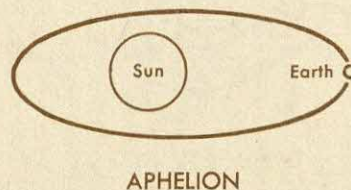
PHYSICS. The opening at the front of an optical instrument, such as a camera or telescope, through which light rays enter.

The APERTURE of most cameras can be adjusted to allow varying amounts of light to reach the film.

aphelion \a-ˈfēl-yən\ *n.*

ASTRONOMY. The portion of a comet's or a planet's elliptical orbit that is farthest from the sun.

Halley's Comet reaches its APHELION in outer space beyond the solar system.



aqua regia

apical dominance \ˈap-i-kəl ˈdām-(ə-)nən(t)s\

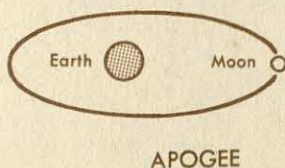
BOTANY. The repressed growth of the lateral buds of a plant, believed to be caused by auxin originating in apical buds.

Some botanists believe that APICAL DOMINANCE is partially caused by a restricted supply of nutrients.

apogee \ˈap-ə-(.)jē\ *n.*

1. ASTRONOMY. The part of the moon's elliptical orbit that is farthest from the earth. 2. ASTRONAUTICS. The part of an artificial satellite's elliptical orbit that is farthest from the earth.

At APOGEE, the moon is 252,710 miles from the earth.



apothem \ˈap-ə-,them\ *n.*

MATHEMATICS. The radius of a circle inscribed in a regular polygon.

The APOTHEM drawn to a side of a regular polygon is the perpendicular bisector of that side.

apparent magnitude \ə-ˈpar-ənt ˈmag-nə-,t(y)üd\

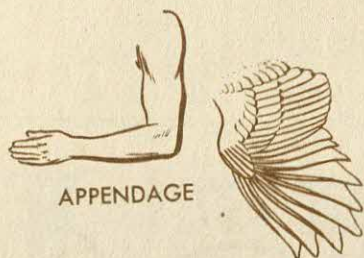
ASTRONOMY. The brightness of a celestial body considered without regard to its distance from earth.

While the sun is far from the largest star, it has the greatest APPARENT MAGNITUDE.

appendage \ə-ˈpen-dij\ *n.*

ANATOMY and ZOOLOGY. An extension of an animal's body, such as an arm, a leg, a wing or an antenna.

The wing of a bird is an APPENDAGE usually used in flying.



appendix \ə-ˈpen-diks\ *n.*

ANATOMY. A common term for vermiform appendix. See *vermiform appendix*.

apsis \ˈap-səs\ *n.*

ASTRONOMY. The point on an orbit where the distance of the orbiting body from the orbited body is either greatest or least.

In the earth's orbit around the sun, the nearest APSIS of the earth is called the perigee.

aqua \ˈak-wə\ *n.*

MEDICINE. Water.

AQUA is a term used in pharmacy for a liquid or solution.

aqua regia \ˈak-wə ˈrē-j(ē-)ə\

CHEMISTRY. A mixture of one part concentrated nitric acid and three or four parts concentrated hydrochloric acid. It is a foam-

aquatic

ing, very corrosive yellow liquid that dissolves gold, platinum and other metals, and is sometimes used in the etching process.

Alchemists knew and used AQUA REGIA as early as the ninth century and named it "royal water" because of its mysterious ability to dissolve gold.

aquatic \ə-'kwät-ik\ *adj.*

Of or pertaining to water, or to things living in water.

The pond lily is an AQUATIC plant.

aqueous \'ā-kwē-əs\ *adj.*

Like water; also, made with water, or from it.

An antiseptic in AQUEOUS solution is used for eye drops.

aqueous humor \'ā-kwē-əs 'hyü-mər\

PHYSIOLOGY. A clear, watery liquid that occurs between the cornea and lens of the eye.

AQUEOUS HUMOR maintains the shape of the cornea in the eye.

Arabic numerals \'ar-ə-bik 'n(y)üm-(ə-)rəlz\

The ten symbols, 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9, that are the basis of our decimal system of numeration.

Computations can be performed more easily by using ARABIC NUMERALS than by using Roman numerals.

arboreal \är-'bör-ē-əl\ *adj.*

Pertaining to, or of the nature of, trees; also, tree-dwelling.

Some monkeys are arboreal animals.

arc \'ärk\ *n.*

1. PHYSICS. A low-voltage, high-current electrical discharge between two electrodes. 2. MATHEMATICS. A portion of a curved line.

An ARC is used in welding to fuse metals.

archegonium \,är-ki-'gō-nē-əm\ *n.*

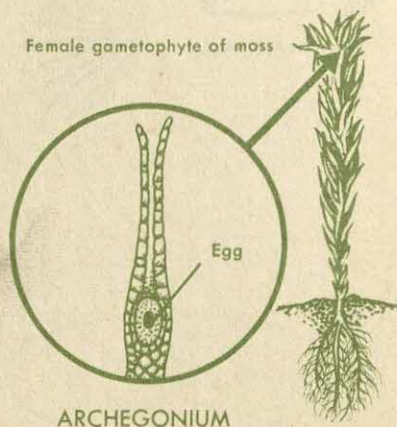
BOTANY. An organ of some nonflowering plants, such as mosses and ferns, in which female reproductive cells are formed.

Each ARCHEGONIUM holds a single reproductive cell.

archipelago \,är-kə-'pel-ə-,gō\ *n.*

EARTH SCIENCE. An area of water containing a group of islands; also, the islands themselves.

The Alexander ARCHIPELAGO, that is part of Alaska, contains about 1,100 islands.



arctic \ 'ärk-tik\ *adj.*

EARTH SCIENCE. Of or pertaining to the North Pole or north polar region.

Weather research in ARCTIC areas has improved weather prediction in temperate areas.

area \ 'ar-ē-ə\ *n.*

MATHEMATICS. The number, whole or fractional, of unit squares enclosed by the perimeter of a plane geometric figure.

The AREA of a rectangle 3 feet wide by 4 feet long is 12 square feet.

arête \ ə-'rät\ *n.*

EARTH SCIENCE. A rugged crest or ridge of a mountain range formed by glacial action.

An ARÊTE is a feature of a geologically-youthful mountain range.

argon \ 'är-gän\ *n.*

CHEMISTRY. An odorless, colorless, gaseous element that occurs in air and in other natural gas mixtures. Symbol, Ar; atomic number, 18; atomic weight, 39.95.

Light bulbs are usually filled with ARGON, or a mixture of argon and nitrogen.

arid region \ 'ar-əd 'rē-jən\

EARTH SCIENCE. An area that has insufficient rainfall to support vegetation; generally, a desertlike region.

Animals that live in an ARID REGION obtain water from their food.

arithmetic mean \,ar-ith-'met-ik 'mēn\

MATHEMATICS. Average; the sum of a set of quantities divided by the number of quantities in the set.

The ARITHMETIC MEAN of the sum of 6 and 18 is 12.

arithmetic progression \,ar-ith-'met-ik prə-'gresh-ən\

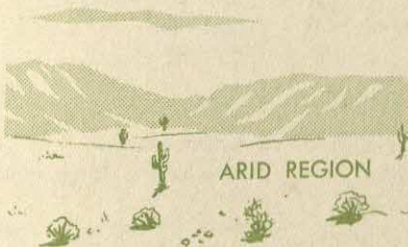
MATHEMATICS. A group of successively greater or smaller numbers proceeding by a fixed amount, such as the series 3, 6, 9, 12.

The sizes of ready-made clothing frequently increase in an ARITHMETIC PROGRESSION, such as sizes 10, 12, 14, 16 and 18.

arithmetic unit \,ar-ith-'met-ik 'yü-nät\

ENGINEERING and MATHEMATICS. That part of a digital computer where mathematical computations are performed.

The ARITHMETIC UNIT of many digital computers feeds its answers to a memory device.



ABBREVIATIONS

A	ampere	ft-c	footcandle	m ²	square meter
Å	Angstrom unit	ft-lb	foot-pound	m ³	cubic meter
abs	absolute			ma	milliampere
a-c	alternating current (as an adjective)	G	universal gravitational constant	Mev	one million electron volts
amu	atomic mass unit	g	gram	mg	milligram
atm	atmosphere	gal	gallon	mh	millihenry
at. wt	atomic weight	g-cal	gram-calorie	mi	mile
AU	astronomical unit	gpm	gallons per minute	mi ²	square mile
avdp	avoirdupois	gps	gallons per second	min	minute
		hr	hour	m-kg	meter-kilogram
Bev	one billion electron volts	hν	photon energy	ml	milliliter
bhp	brake horsepower	hp	horsepower	mm	millimeter
bhp-hr	brake horsepower-hour	Hz	hertz (cycles per second)	mm ²	square millimeter
bp	boiling point			mm ³	cubic millimeter
Btu	British thermal unit			mμ	millimicron
		I	electric current	mph	miles per hour
C	temperature Celsius; temperature Centigrade	ID	inside diameter	mphps	miles per hour per second
c	candle	in.	inch	mv	millivolt
cal	calorie	in. ²	square inch		
cfm	cubic feet per minute	in. ³	cubic inch	N	Avogadro's constant
cfs	cubic feet per second	in.-lb	inch-pound	n!	factorial <i>n</i>
cgs	centimeter-gram-second (system)	ips	inches per second		
cl	centiliter	j	joule	OD	outside diameter
cm	centimeter			oz	ounce
cm ²	square centimeter	K	temperature Kelvin (absolute)		
cm ³	cubic centimeter	kcal	kilocalorie	pH	rating on acid-alkaline scale
coef	coefficient	kg	kilogram	ppm	parts per million
colog	cologarithm	kg-cal	kilogram-calorie	psi	pounds per square inch
cos	cosine	kg-m	kilogram-meter	psia	pounds per square inch absolute
cot	cotangent	kg/m ³	kilograms per cubic meter		
cp	candlepower	kgps	kilograms per second	R	temperature Reaumur; resistance
csc	cosecant	km	kilometer	RA	right ascension
cu	cubic	kv	kilovolt	rpm	revolutions per minute
cu ft	cubic foot	kw	kilowatt	rps	revolutions per second
		kwhr	kilowatt-hour		
db	decibel	l	liter; lumen	sec	secant; second
d-c	direct current (as an adjective)	lat	latitude	sin	sine
doz	dozen	lb	pound	sp gr	specific gravity
		lb-ft	pound-foot	sq	square
E	electromotive force	lb/ft ²	pounds per square foot		
e	the base of the system of natural logarithms	lb/ft ³	pounds per cubic foot	tan	tangent
ev	electron volt	lb-in.	pound-inch		
		l-hr	lumen-hour	V	volt
F	temperature Fahrenheit	lin ft	linear foot	VA	volt-ampere
fp	freezing point	log	logarithm (common)		
fpm	feet per minute	log _e	logarithm (natural)	W	watt; work
fps	feet per second	long.	longitude		
ft	foot; feet			yd	yard
ft ²	square foot	m	meter; minute (time, in astronomical circles)	yd ²	square yard
ft ³	cubic foot			yd ³	cubic yard

SCIENTIFIC SYMBOLS AND ABBREVIATIONS

α	alpha particle	Σ	the sum of	[]	molar concentration
β; β ⁻	beta particle	σ	nuclear cross section (barns); area	+	positive electric charge; mixed with; plus
β ⁺	positron	Ω	electrical resistance (ohms)	-	negative electric charge; single covalent bond; minus
γ	gamma radiation	ω	angular speed; angular velocity	=	equals; double covalent bond; produces
Δ	a small change; heat	'	minute (angular measure)	≠	does not equal
λ	wavelength; radioactive-decay constant	"	second (angular measure)	≡	triple covalent bond
ma	milliampere	♂	male	→	produces; forms; chemical reaction
μc	microcurie	♀	female	⇌	reversible chemical reaction
μf	microfarad	>	is greater than	↑	gas produced by a chemical reaction
μin.	microinch	<	is less than	↓	precipitate produced by a chemical reaction
μm	micron	α	is proportional to	°	radioactive substance (follows symbol of element; example, Cl°)
μμ	micromicron	∞	infinity		
μμf	micromicrofarad	√	square root of		
ν	frequency; neutrino	°	degrees; temperature; angle measurement (example, 30°)		
π	3.14159; osmotic pressure				